U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-264 284

HP-65 Programmable Pocket Calculator Applied to Air Pollution Measurement Studies: Stationary Sources

Southern Research Inst, Birmingham, Ala

Prepared for

Industrial Environmental Research Lab, Research Triangle Park, N C

Oct 76

PB 264 284

EPA-600/8-76-002
October 1976

HP-65 PROGRAMMABLE POCKET CALCULATOR APPLIED TO AIR POLLUTION MEASUREMENT STUDIES: Stationary Sources

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/8-76-002	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE HP-65 Programmable Pocket Calculator Applied to Air Pollution Measurement Studies: Stationary Sources		5. REPORT DATE October 1976
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) James W. Ragland, Kenneth M. Cushing, Joseph D. McCain, and Wallace B. Smith		8. PERFORMING ORGANIZATION REPORT NO. SORI-EAS-76-447
9. PERFORMING ORGANIZATION NAME AND ADDRESS Southern Research Institute 2000 Ninth Avenue, South Birmingham, Alabama 35205		10. PROGRAM ELEMENT NO. EHE624
		11. CONTRACT/GRANT NO. 68-02-2131
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED User Handbook; 11/75-10/76
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer for this handbook is D. B. Harris, 919/549-8411 Ext 2557, Mail Drop 62.

16. ABSTRACT The handbook is intended for persons concerned with air pollution measurement studies of stationary industrial sources. It gives detailed descriptions of 22 different programs written specifically for the Hewlett Packard Model HP-65 card-programmable pocket calculator. For each program there is: a general description, formulas used in the problem solution, numerical examples, user instructions, and program listings. Areas covered include: Methods 1 through 8 of the EPA Test Codes (Federal Register, 12/23/71), calibration of a flame photometric detector by the permeation tube technique, determination of channel concentrations for a droplet measuring device, resistivity and electric field strength measurements, determination of stack velocity, nozzle diameter, and isokinetic delta H for a high volume stack sampler, and several programs for cascade impactors. Cascade impactor programs include: determination of impactor stage cut points, calculation of the square root of the Stokes number for round-jet and for rectangular-slot geometries, nozzle selection and determination of delta H for isokinetic sampling, determining of sampling time required to collect 50 mg total sample, determination of impactor flow rate, sample volume, and mass loading, and calculation of cumulative concentration curves and their differentials.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Photometry	Air Pollution Control	13B	
Measurement	Flue Gases	Stationary Sources	14B	21B
Calculators	Sampling	Pocket Calculators	09B	
Cards	Impactors	Card Programming		
Handbooks	Kinetics	Hewlett Packard (HP-65)	05B	20K
Instructions	Stokes Law (Fluid Mechanics)	Cascade Impactors		20D

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 124
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

EPA-600/8-76-002
October 1976

HP-65 PROGRAMMABLE POCKET CALCULATOR APPLIED TO AIR POLLUTION MEASUREMENT STUDIES: STATIONARY SOURCES

by

James W. Ragland, Kenneth M. Cushing,
Joseph D. McCain, and Wallace B. Smith

Southern Research Institute
2000 Ninth Avenue, South
Birmingham, Alabama 35205

Contract No. 68-02-2131
Program Element No. EHE624

EPA Project Officer: D. Bruce Harris

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

REVIEW NOTICE

This document has been reviewed by the U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

ABSTRACT

This report is intended to provide a useful tool to persons concerned with Air Pollution Measurement Studies of Stationary Industrial Sources. Detailed descriptions are given for twenty two separate programs that have been written specificly for the Hewlett Packard Model HP-65 card programmable pocket calculator. Each program includes a general description, formulas used in the problem solution, numerical examples, user instructions, and program listings. Areas covered include the following: Methods 1 through 8 of the EPA Test Codes (Federal Register, December 23, 1971), calibration of a flame photometric detector by the permeation tube technique, determination of channel concentrations for a droplet measuring device, resistivity and electric field strength measurments, determination of stack velocity, nozzle diameter, and isokinetic delta H for a high volume stack sampler, and several programs for cascade impactors. Those for cascade impactors include: determination of impactor stage cut points, calculation of the square root of the Stokes number for round jet and for rectangular slot geometries, nozzle selection and determination of delta H for isokinetic sampling, determination of sampling time required to collect 50 mg total sample, determination of impactor flow rate, sample volume, and mass loading, and calculation of cumulative concentration curves and their differentials.

CONTENTS

PAGE

Abstract iii

List of Programs v

Acknowledgment vi

SECTIONS

I Introduction 1

II Environmental Protection Agency: Standards of Performance for New Stationary Sources; Appendix - Test Methods (Federal Register Vol. 36, No. 247, Part II, December 23, 1971) 4

III Cascade Impactors 25

IV Others 68

V Appendices 84

A. Entering a Program Card 85

B. Brief Operating Instructions 86

C. Program Listings 87

D. Unit Conversion Table 115

PROGRAMS

NUMBER		PAGE
APol–01	Method 1 - Sample and Velocity Traverses for Stationary Sources	4
APol–02	Method 2 - Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)	7
APol–03	Method 3 - Gas Analysis for Carbon Dioxide, Excess Air, and Dry Molecular Weight	10
APol–04	Method 4 - Determination of Moisture in Stack Gases	12
APol–05	Method 5 - Determination of Particulate Emissions from Stationary Sources	14
APol–06	Method 6 - Determination of Sulfur Dioxide Emissions from Stationary Sources	18
APol–07	Method 7 - Determination of Nitrogen Oxide Emissions from Stationary Sources	20
APol–08	Method 8 - Determination of Sulfuric Acid Mist and Sulfur Dioxide Emissions from Stationary Sources	22
APol–09	Cascade Impactor Operation	25
APol–10	Impactor Flow Rate Given Orifice ΔH	39
APol–11	Impactor Flow Rate, Given Gas Velocity and Nozzle Diameter	42
APol–12	Impactor Sampling Time to Collect 50 Milligrams	44
APol–13	Impactor Flow Rate, Sample Volume, Mass Loading	46
APol–14	Impactor Stage D_{50}	50
APol–15	$\sqrt{\Psi}$ Calculation - Round Jets	57
APol–16	$\sqrt{\Psi}$ Calculation - Rectangular Slots	60
APol–17	Cumulative Concentration vs D_{50} and $\Delta M/\Delta \log D$ vs Geometric Mean Diameter	63
APol–18	Mean, Standard Deviation, 90/95% Confidence Interval, Mean ± CI	68
APol–19	Resistivity and Electric Field Strength	71
APol–20	Channel Concentrations for the KLD Droplet Measuring Device (1-600 μm) DC-1	73
APol–21	Aerotherm High Volume Stack Sampler; Stack Velocity, Nozzle Diameter, Isokinetic ΔH	75
APol–22	Flame Photometric Detector Calibration by Permeation Tube Technique	81

ACKNOWLEDGMENT

The assistance of Mr. Ray Wilson and Dr. Herbert Miller in the preparation of this manuscript is greatly appreciated. A special thanks is given to Mrs. Ann Billingsley for her work as typist and to Mr. Don Davis as layout artist.

SECTION I

INTRODUCTION

GENERAL

The programs in this manual have been selected from the areas of Compliance Testing, Cascade Impactor Operation, Mass Train Operation, Resistivity Measurements, etc., and written for the Hewlett Packard Model HP-65 card programmable pocket calculator. A manual giving many of these same programs in a modified form for use with a Hewlett Packard Model HP-25 manually programmable pocket calculator is also available. Each program herein includes a general description, formulas used in the problem solution, numerical examples, and user instructions. Program listings and register allocations are given in Appendix C at the back of this manual.

At the time of this writing the December 23, 1971 Federal Register (Volume 36, No. 247, Part II), "Standards of Performance for New Stationary Sources; Appendix - Test Methods" sets forth the official EPA test methods. Consequently, Section II of this text (programs APol-01 through APol-08) has been based on the December 1971 document except as noted below.

A proposed amendment to the test methods had been set forth in the June 8, 1976 Federal Register (Volume 41, No. 111) and minor changes to the programs contained in this document may be required when the modified procedures are adopted.

In contrast to the equations set forth in the December 23, 1971 Federal Register, the equations in this text use 68°F (20.0°C), as Standard Temperature rather than 70°F (21.1°C).

The difference in absolute temperature, at constant pressure, between 20.0°C and 21.1°C introduces only a very slight change in the sample volume. The conversion factors are:

$$V_{(21.1°C)} = 1.0038 \quad V_{(20.0°C)}$$

and

$$V_{(20.0°C)} = 0.9962 \quad V_{(21.1°C)}.$$

For the convenience of the user, most input data requirements call for English units. The output for such cases is also in English units; however, the program steps provide for direct conversion to metric units for reporting purposes. The terms "standard conditions" and "normal conditions" are used interchangeably and refer to 68°F (20.0°C) temperature and 29.92 inches Hg (760 Torr) pressure. Most temperature values are entered in °F (or °C) rather than °R (or °K) although the formula being worked may specify "absolute" temperature. Conversion to "absolute" units is accomplished internally.

FORMAT OF USER INSTRUCTIONS

The following is an example of a set of user instructions.

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	Store variables	H	↑		
		B	↑		
		d	A		3
3	Compute E	(H)	STO	2	
		(B)	STO	7	
		(d)	STO	1	
			B		E
4	Compute $(\sqrt{\Delta P})_{avg}$, for $(\Delta P_i, R_i)$	(E)	STO	4	
	a. Sum data sets	ΔP_i	↑		
	(Do i = 1 → N)	R_i	C		
	b. Compute $(\sqrt{\Delta P})_{avg}$		D		$(\sqrt{\Delta P})_{avg}$
5	Compute γ	$((\sqrt{\Delta P})_{avg})$	STO	5	
		(E)	STO	4	
		N	R/S		γ
6	(For different γ, store new values as				
	required then proceed to Line 4)				

To follow the instructions, start with line 1 and read from left to right, performing the indicated operations as you proceed.

Lines are read in sequential order except where the INSTRUCTIONS column directs otherwise. Repeated processes used in most cases for a long string of input/output data are outlined with a bold border together with a "Do" instruction. For example,

$$\text{Do } i = 1 \rightarrow N$$

means to execute the loop N times. On the first pass, the dummy variable i takes on the value 1; on the second pass i takes on the value 2, etc.

Normally, as in the above example, the first instruction is to "Load Program Card" which means load the preprogrammed magnetic card (see Appendix A: "Entering a Program Card"). Some instructions are self contained and can be carried out by simply reading the INSTRUCTIONS column alone, (e.g., "Load Program Card"). But some instructions depend on the information supplied by the DATA and/or KEYS columns. In line 2 of the example "Store variables" appears in the INSTRUCTIONS section and H, B, and d appear in the DATA section. The keystroke symbols [↑] and [A] appear in the KEYS section. This means that to "Store variables", one must load the appropriate value for the variable H and press [↑], load the appropriate value for the variable B and press [↑], then load the appropriate value for the variable d and press [A]. The number "3.00" will be displayed when this sequence of program instructions has been completed.

The DATA column specifies the input data to be supplied. Symbols are defined in the text and correct units are shown in the **Example** section.

A special notational format has been adopted which allows the operator to modify the sequence of operating instructions. The use of parentheses around a variable (as shown in the DATA column for line 3) indicates that when operating instructions are followed in the indicated sequence the appropriate value will have already been loaded in the correct storage register. Operations shown in parentheses are only used to change the magnitude of variables already stored by previous entry or calculation. **OPERATIONS SHOWN IN PARENTHESES ARE OMITTED FOR NORMAL OPERATION.**

For added convenience, most programs herein have been designed so as to frequently allow the substitution [R/S] for a specific program address (such as [B], [C], etc.). As shown in our example, [R/S] could be used in place of both [B] and [C], however only the specific program address [D] can be used to branch out of the Do Loop. The operator should use the Example section of each program to determine when substitution is desirable. The command [R/S] restarts program execution from wherever the program pointer happens to be positioned. When an unlabeled specific address is called for, program execution begins from the top of memory.

For the convenience of the reader, Appendix B gives a brief review of operating instructions for the HP-65. For more extensive instruction the reader is referred to the HP-65 owner's handbook.

SECTION II

METHOD 1

SAMPLE AND VELOCITY TRAVERSES FOR STATIONARY SOURCES

TRAVERSE POINTS-CIRCULAR DUCT

For a circular duct, the distance from flange to traverse point (t_j as shown below) is given by:

$$t_j = \left(d + \frac{D}{2}\right) \pm \alpha_i \qquad (1\text{-}1)$$

where

d = distance from the inside of the duct to the top of the flange

D = inside diameter of the duct

α_i = is given by:

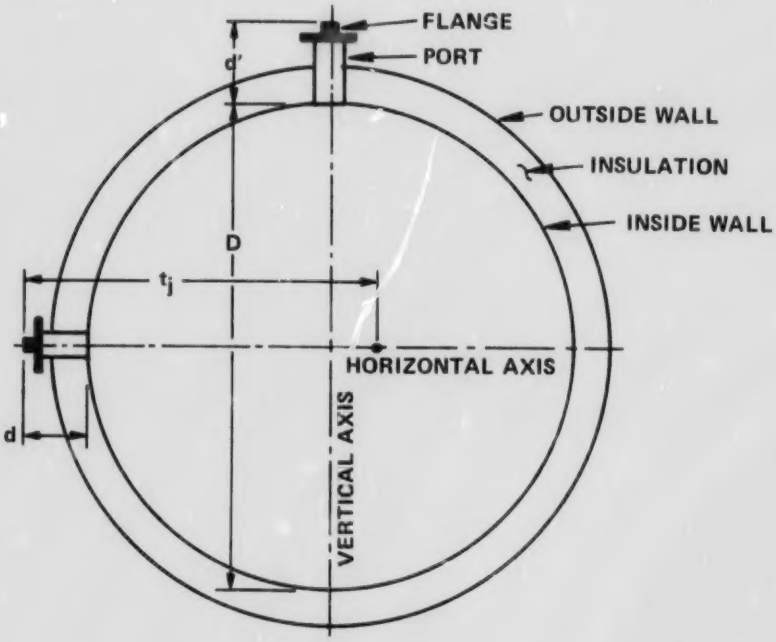
$$\alpha_i = (D/2)\sqrt{(2n_i - 1)/K} \quad \text{for } n_i = 1, 2, \ldots \ell$$

where

K = number of traverse points on a given axis, an even integer

ℓ = $K/2$

n_i = an integer having values 1, 2, ... ℓ



Thus for K traverse points on a given axis (i.e., horizontal or vertical) we have "flange to point" distances, t_j, as follow:

$$(\text{let } C = d + D/2)$$

$$t_1 = C - \alpha_\ell$$
$$t_2 = C - \alpha_{\ell-1}$$
$$t_3 = C - \alpha_{\ell-2}$$

$$t_p = C - \alpha_1$$
$$t_{p+1} = C + \alpha_1$$
$$t_{p+2} = C + \alpha_2$$

$$t_{K-1} = C + \alpha_{\ell-1}$$
$$t_K = C + \alpha_\ell$$

Note:
- The choice of units for D and d fix the units of t_j. Do not mix units.
- If "d" is the same for both ports (horizontal axis and vertical axis, see illustration) the same "t_j's" may be used on either axis. If $d \neq d'$, a new set (t_j') must be calculated using d'.

Reference: Standard Method for Sampling Stacks for Particulate Matter, D 2928-71. In: 1971 Annual Book of ASTM Standards, Part 23. Philadelphia, Pa., 1971, p. 835.

Example:

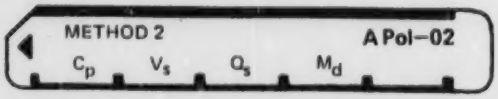
d = 1.5 feet
D = 20 feet
K = 10 (i.e., 10 points on the horizontal axis)

t_1 = 2.01 feet
t_2 = 3.13 feet
t_3 = 4.43 feet
t_4 = 6.02 feet
t_5 = 8.34 feet
t_6 = 14.66 feet
t_7 = 16.98 feet
t_8 = 18.57 feet
t_9 = 19.87 feet
t_{10} = 20.99 feet
0.00 indicates END

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
1	Load card			
2	Compute "flange to point" distances,	d	↑	
	t_j;	D	↑	
	(Note: K points on a single axis, K	K	A	t_1
	must be an even number)		R/S	t_2
			R/S	t_3
	(Note: 0.0 indicates end)		⋮	⋮
			R/S	t_k
			R/S	0.0

METHOD 2

DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE (TYPE S PITOT TUBE)



As described in Volume 36, No. 247, Part II of the Federal Register, December 23, 1971, the coefficient (C_p) for a Type S pitot tube can be determined by simultaneous readings from a standard type pitot tube from the following equation:

$$C_{p_{test}} = C_{p_{std}} \sqrt{\frac{\Delta p_{std}}{\Delta p_{test}}} \qquad (2\text{-}1)$$

where

$C_{p_{test}}$ = pitot tube coefficient of Type S pitot tube, dimensionless

$C_{p_{std}}$ = pitot tube coefficient of standard (if unknown use 0.99) type pitot tube, dimensionless

Δp_{std} = velocity head measured by standard type pitot tube, inches H_2O

Δp_{test} = velocity head measured by Type S pitot tube, inches H_2O

Using a calibrated Type S pitot tube, the stack gas velocity, $(V_s)_{avg}$, can be calculated from:

$$(V_s)_{avg} = K_p \; C_{p_{test}} \; (\sqrt{\Delta p})_{avg} \sqrt{\frac{(T_s)_{avg}}{P_s \; M_s}} \qquad (2\text{-}2)$$

where

$(V_s)_{avg}$ = average stack gas velocity, actual f.p.s.

K_p = 85.48 for the units given herein

$C_{p_{test}}$ = pitot tube coefficient, dimensionless

$(T_s)_{avg}$ = average absolute stack gas temperature, °R

$(\sqrt{\Delta p})_{avg}$ = average velocity head of stack gas, inches H_2O

P_s = stack gas pressure, absolute, inches Hg

M_s = molecular weight of stack gas, wet, lb/lb-mole, given by:

$$M_s = M_d(1\text{-}B_{wo}) + 18\, B_{wo}$$

where

M_d = dry molecular weight of stack gas (from Method 3), lb/lb-mole

B_{wo} = fraction by volume of water vapor in the gas stream (from Method 4), dimensionless

The stack gas volumetric flow rate, Q_s, is given by:

$$Q_s = 3600\ (1-B_{wo})(V_s)_{avg}\ A\left(\frac{T_{std}}{(T_s)_{avg}}\right)\left(\frac{P_s}{P_{std}}\right) \qquad (2\text{-}3)$$

where

Q_s = volumetric flow rate, dry basis, standard (normal) conditions (528°R, 29.92 inches Hg), ft^3/hr (i.e., DSCFH)

A = cross-sectional area of stack, ft^3

T_{std} = 528°R, absolute temperature at standard (normal) conditions

P_{std} = 29.92 inches Hg, absolute pressure at standard (normal) conditions

B_{wo}, $(V_s)_{avg}$, $(T_s)_{avg}$ and P_s are as defined above

Note:
- 1.00 ft/sec = 0.3048 m/sec
- 1.00 ft^3/hr = 28.32 l/hr = 0.02832 m^3/hr

Example:

$C_{p_{std}}$ = 0.99
Δp_{std} = 0.31 inches H_2O
Δp_{test} = 0.42 inches H_2O

→ $C_{p_{test}}$ = 0.851

%CO = 1%
$\%N_2$ = 79%
$\%O_2$ = 6%
$\%CO_2$ = 13%

→ M_d = 30.04 lb/lb-mole

$(T_s)_{avg}$ = 350°F
$(\sqrt{\Delta p})_{avg}$ = 0.59 inches $H_2O^{1/2}$
P_s = 29.00 inches Hg
B_{wo} = 0.10

→ $(V_s)_{avg}$ = 42.2 f.p.s.
(= 12.9 m/sec)

A = 1,200 ft^2

→ Q_s = 1.04×10^8 DSCFH
(= 2.94×10^9 l/hr)

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	Compute pitot tube coefficient, $C_{p_{test}}$	$C_{p_{std}}$	↑		
		Δp_{std}	↑		
		Δp_{test}	A		$C_{p_{test}}$
3	Compute M_d	%CO	↑		
		$\%N_2$	↑		
		$\%O_2$	↑		
		$\%CO_2$	D		M_d
4	a. Compute stack gas velocity, $(V_s)_{avg}$	$(T_s)_{avg}$	STO	2	
		$(\sqrt{\Delta p})_{avg}$	STO	3	
		$(C_{p_{test}})$	STO	4	
		P_s	STO	5	
		(M_d)	STO	6	
		B_{wo}	STO	7	
			B		$(V_s)_{avg}$
	To convert ft/sec → m/sec	0.3048	X		m/sec
	b. Compute stack gas volumetric	$((V_s)_{avg})$	STO	8	
	flow rate, Q_s	A	STO	9	
			C		Q_s
	To convert ft^3/hr → l/hr	28.32	X		l/hr
5	(For different traverse data, store the				
	new values in the appropriate				
	registers and press B)				

METHOD 3

GAS ANALYSIS FOR CARBON DIOXIDE, EXCESS AIR, AND DRY MOLECULAR WEIGHT

As described in Volume 36, No. 247, Part II of the Federal Register, December 23, 1971, the percent excess air, %EA, is given by the following:

$$\%EA = \frac{(\%O_2) - 0.5\,(\%CO)}{0.264\,(\%N_2) - (\%O_2) + 0.5\,(\%CO)} \times 100\% \qquad (3\text{-}1)$$

where

$\%EA$ = percent excess air
$\%O_2$ = percent oxygen by volume, dry basis
$\%N_2$ = percent nitrogen by volume, dry basis
$\%CO$ = percent carbon monoxide by volume, dry basis
0.264 = ratio of oxygen to nitrogen in air by volume

The dry molecular weight, M_d, is given by:

$$M_d = 0.44\,(\%CO_2) + 0.32\,(\%O_2) + 0.28\,(\%N_2 + \%CO) \qquad (3\text{-}2)$$

where

M_d = dry molecular weight, lb/lb-mole
$\%CO_2$ = percent carbon dioxide by volume, dry basis
$\%O_2$ = percent oxygen by volume, dry basis
$\%N_2$ = percent nitrogen by volume, dry basis
$\%CO$ = percent carbon monoxide by volume, dry basis
0.44 = molecular weight of carbon dioxide divided by 100
0.32 = molecular weight of oxygen divided by 100
0.28 = molecular weight of nitrogen and CO divided by 100

Note: 1.0 lb/lb-mole = 1.0 gm/gm-mole = 1.0 amu

Example:

$\%CO = 1\%$
$\%N_2 = 79\%$
$\%O_2 = 4\%$
$\%CO_2 = 16\%$

→ $\%EA = 20.17\%$
$M_d = 30.72$ lb/lb-mole

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	Store variables	%CO	↑		
		$\%N_2$	↑		
		$\%O_2$	↑		
		$\%CO_2$	A		3
3	a. Compute % excess air, %EA	(%CO)	STO	1	
		($\%N_2$)	STO	2	
		($\%O_2$)	STO	3	
			B		%EA
	b. Compute dry molecular weight, M_d	($\%CO_2$)	STO	4	
			C		M_d

METHOD 4

DETERMINATION OF MOISTURE IN STACK GASES

As described in Volume 36, No. 247, Part II of the Federal Register, December 23, 1971, the volume of water vapor collected, V_{wc}, is given by:

$$V_{wc} = (0.0472\ ft^3/ml)\left(V_f - V_i\right) \tag{4-1}$$

where

V_{wc} = volume of water vapor collected (standard conditions, 528°R, 29.92 inches Hg), ft^3

V_f = final volume of impinger contents, ml

V_i = initial volume of impinger contents, ml

The dry gas volume through the meter, at standard conditions, V_{me}, is given by:

$$V_{me} = (17.65°R/in.\ Hg)\left(\frac{V_m P_m}{T_m}\right) \tag{4-2}$$

where

V_{me} = dry gas volume through meter at standard conditions, ft^3

V_m = dry gas volume measured by meter, ft^3

P_m = barometric pressure at the dry gas meter, inches Hg

T_m = absolute temperature at meter, °R

The moisture content, B_{wo}, is given by:

$$B_{wo} = \left(\frac{V_{wc}}{V_{wc} + V_{me}}\right) + 0.025 \tag{4-3}$$

where

B_{wo} = fraction by volume of water vapor in the gas stream, dimensionless

V_{wc} = volume of water vapor collected (standard conditions), ft^3

0.025 = approximate volumetric proportion of water vapor in the gas stream leaving the impingers

V_{me} is as defined in (4-2) above.

Note: 1.00 ft^3 = 28.32 liters

Example:

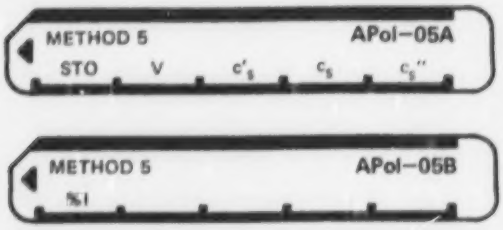
V_f = 12.5 ml (total)
V_i = 10.0 ml (total)
V_m = 1.00 ft^3
P_m = 29.00 in. Hg
T_m = 100°F

→ V_{wc} = 0.119 ft^3 (= 3.36 liters)
V_{me} = 0.914 ft^3 (= 25.9 liters)
B_{wo} = 0.14, dimensionless

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	Store variables	V_f	↑		
		V_i	A		2
		V_m	↑		
		P_m	↑		
	(°F)	T_m	R/S		3
3	Compute the volume of water vapor	(V_f)	STO	1	
	collected	(V_i)	STO	2	
			B		V_{wc}
4	Compute the dry gas volume through	(V_m)	STO	3	
	the meter	(P_m)	STO	4	
		(T_m)	STO	5	
			C		V_{me}
5	Compute the proportion by volume of	(V_{wc})	STO	6	
	water vapor in the gas stream, B_{wo}	(V_{me})	STO	7	
			D		B_{wo}
6	To convert ft^3 to liters	ft^3	E		liters

METHOD 5

DETERMINATION OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES



As described in Volume 36, No. 247 Part II of the Federal Register, December 23, 1971, the sample volume measured by the dry gas meter, corrected to standard conditions (68°F, 29.92 inches Hg) is given by:

$$V_{m_{std}} = \left(17.65 \frac{°R}{in.\ Hg}\right) V_m \left(\frac{P_{bar} + \frac{\Delta H}{13.6}}{T_m}\right) \qquad (5\text{-}1)$$

where

$V_{m_{std}}$ = volume of gas sample through the dry gas meter (standard conditions), ft^3
V_m = volume of gas sample through the dry gas meter (meter conditions), ft^3
T_m = average dry gas meter temperature, °R
P_{bar} = barometric pressure at the orifice meter, inches Hg
ΔH = average pressure drop across the orifice meter, inches H_2O

The volume of water vapor in the gas sample, corrected to standard conditions, is given by:

$$V_{w_{std}} = \left(0.0472 \frac{ft^3}{ml}\right) V_{\ell c} \qquad (5\text{-}2)$$

where

$V_{w_{std}}$ = volume of water vapor in the gas sample (standard conditions), ft^3
$V_{\ell c}$ = total volume of liquid collected in impingers and silica gel, ml

The fraction by volume of water vapor in the gas stream is given by:

$$B_{wo} = \frac{V_{w_{std}}}{V_{m_{std}} + V_{w_{std}}} \qquad (5\text{-}3)$$

where

B_{wo} = fraction by volume of water vapor in the gas stream, dimensionless
$V_{m_{std}}$ and $V_{w_{std}}$ are as given in equations (5-1) and (5-2) respectively.

The concentration of particulate matter in stack gas, dry basis, is given by:

$$c'_s = \left(0.0154 \frac{gr}{mg}\right)\left(\frac{M_n}{V_{m_{std}}}\right) \tag{5-4}$$

where

c'_s = concentration of particulate matter in stack gas, gr/S.C.F., dry basis
M_n = total amount of particulate matter collected, mg
$V_{m_{std}}$ is as given by equation (5-1).

Changing units, we can express c'_s in terms of lb/S.C.F., dry basis, as follows:

$$c_s = \left(2.205 \times 10^{-6} \frac{lb}{mg}\right) \frac{M_n}{V_{m_{std}}} \tag{5-5}$$

where

c_s = concentration of particulate matter in stack gas, lb/S.C.F., dry basis
M_n and $V_{m_{std}}$ are as given in equation (5-4).

We can also express c'_s in terms of gm/SCM, dry basis, as follows:

$$c''_s = \left(0.03532 \frac{gm \cdot SCF}{mg \cdot SCM}\right) \frac{M_n}{V_{m_{std}}}$$

where

c''_s = concentration of particulate matter in stack gas, gm/SCM, dry basis
M_n and $V_{m_{std}}$ are as given in equation (5-4).

The percent isokinetic sampling is given by:

$$I = \frac{\left(1.677 \frac{min\%}{sec}\right) T_s \left[\left(0.00267 \frac{in.\ Hg\text{-}ft^3}{ml\text{-}^\circ R}\right) V_{\ell c} + \frac{V_m}{T_m}\left(P_{bar} + \frac{\Delta H}{13.6 \frac{in.\ H_2O}{in.\ Hg}}\right)\right]}{\theta\ V_s\ P_s\ A_n} \tag{5-6}$$

where

I = percent of isokinetic sampling, %
$V_{\ell c}$ = total volume of liquid collected in impingers and silica gel, ml
V_m = volume of gas sample through the dry gas meter (meter conditions), ft^3
T_m = absolute average dry gas meter temperature, °R
P_{bar} = barometric pressure at sampling site, inches, Hg
ΔH = average pressure drop across the orifice, inches H_2O
T_s = absolute average stack gas temperature, °R
θ = total sampling time, min
V_s = stack gas velocity (calculated by Method 2, Equation 2-2), ft/sec
P_s = absolute stack gas pressure, inches Hg
A_n = cross-sectional area of nozzle, ft^2

Note:
- $1.00\ gr/ft^3 = 2.288\ gm/m^3$
- $1.00\ lb/ft^3 = 1.602 \times 10^4\ gm/m^3$

Example:

$V_m = 100\ ft^3$
$P_{bar} = 29.5$ inches Hg
$\Delta H = 5.0$ inches H_2O
$T_m = 100°F$

$V_{\ell c} = 50$ ml
$M_n = 100$ mg

→ $V_{m_{std}} = 9.41 \times 10^1$ DSCF
$V_{w_{std}} = 2.36$ DSCF
$B_{wo} = 2.45 \times 10^{-2}$ (dimensionless)
$c'_s = 1.64 \times 10^{-2}$ gr/DSCF
$c_s = 2.34 \times 10^{-6}$ lb/DSCF
$c''_s = 3.75 \times 10^{-2}$ gm/DSCM

$T_s = 300°F$
$\theta = 100$ min
$V_s = 15.00$ ft/sec

$P_s = 29.00$ inches Hg
$A_n = 0.00136\ ft^2$

→ $I = 1.17 \times 10^2\%$

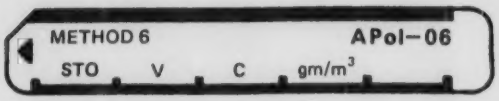
In the above example $I > 110\%$, thus the test results would be rejected and the test repeated.

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
1	Load program card APol–05A		[ ] [ ]	
2	a. Store variables	V_m	[↑] [ ]	
		P_{bar}	[↑] [ ]	
		ΔH	[↑] [ ]	
	(°F)	T_m	[A] [ ]	1
		$V\ell_c$	[↑] [ ]	
		M_n	[R/S] [ ]	2

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
	b. Compute $V_{m_{std}}$	(V_m)	STO 1	
		(P_{bar})	STO 2	
		(ΔH)	STO 3	
		(T_m)	STO 4	
			B	$V_{m_{std}}$
	c. Compute $V_{w_{std}}$	$(V\ell_c)$	STO 5	
			R/S	$V_{w_{std}}$
	d. Compute B_{wo}	$(V_{m_{std}})$	STO 7	
		$(V_{w_{std}})$	R/S	B_{wo}
	e. Compute mass loading, c'_s,	(M_n)	STO 6	
	grains/DSCF	$(V_{m_{std}})$	STO 7	
			C	c'_s
	f. Compute mass loading, c_s,	(M_n)	STO 6	
	lbs/DSCF	$(V_{m_{std}})$	STO 7	
			D	c_s
	g. Compute mass loading, c''_s,	(M_n)	STO 6	
	gm/DSCM	$(V_{m_{std}})$	STO 7	
			E	c''_s
3	Load program card APol–05B			
4	a. Store (If Line No. 2 has been	(V_m)	STO 1	
	omitted, storage registers 1-5	(P_{bar})	STO 2	
	must be loaded first)	(ΔH)	STO 3	
		(T_m)	STO 4	
		$(V\ell_c)$	STO 5	
	b. Compute percent of isokinetic			
	sampling (°F)	T_s	↑	
		θ	↑	
		V_s	A	1
		P_s	↑	
		A_n	R/S	%I
	(Note: Card APol–05B does not			
	overwrite any storage register used			
	by card APol–05A)			

METHOD 6

DETERMINATION OF SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES



As described in Volume 36, No. 247, Part II of the Federal Register, December 23, 1971, the volume of the gas sample through the dry gas meter, corrected to standard conditions (528°R, 29.92 inches Hg), $V_{m_{std}}$, is given by:

$$V_{m_{std}} = \left(17.65 \ \frac{°R}{in.\ Hg}\right)\left(\frac{V_m P_{bar}}{T_m}\right) \qquad (6\text{-}1)$$

where

$V_{m_{std}}$ = volume of gas sample through the dry gas meter (standard conditions), ft^3

V_m = volume of gas sample through the dry gas meter (meter conditions), ft^3

T_m = average dry gas meter temperature, °R

P_{bar} = barometric pressure at the orifice meter, inches Hg

The concentration of sulfur dioxide at standard conditions, dry basis is given by:

$$C_{SO_2} = \left(7.05 \times 10^{-5} \ \frac{lb\text{-}l}{g\text{-}ml}\right)\frac{(V_t - V_{tb})\ N\left(\frac{V_{soln}}{V_a}\right)}{V_{m_{std}}} \qquad (6\text{-}2)$$

where

C_{SO_2} = concentration of sulfur dioxide at standard conditions, dry basis, lb/ft^3

7.05×10^{-5} = conversion factor, including the number of grams per gram equivalent of sulfur dioxide (32 g/g-eq.), 453.6 g/lb, and 1,000 ml/l, lb-l/g-ml

V_t = volume of barium perchlorate titrant used for the sample, ml

V_{tb} = volume of barium perchlorate titrant used for the blank, ml

N = normality of barium perchlorate titrant, g-eq/l

V_{soln} = total solution volume of sulfur dioxide, 50 ml

V_a = volume of sample aliquot titrated, ml

$V_{m_{std}}$ = volume of gas sample through the dry gas meter (standard conditions), ft^3

Note: $1.00\ lb/ft^3 = 1.602 \times 10^4\ gm/m^3$

Example:

$V_m = 1.77\ ft^3$
$P_{bar} = 26.00$ inches Hg
$T_m = 100°F$

$V_t = 5$ ml
$V_{tb} = 0.1$ ml
$N = 0.005$ ml

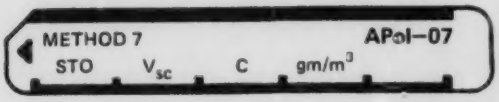
$V_{soln} = 50$ ml
$V_a = 2$ ml

→ $V_{m_{std}} = 1.45\ ft^3$
$C_{SO_2} = 2.98 \times 10^{-5}\ lb/ft^3$
$= 4.77 \times 10^{-1}\ gm/m^3$

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	Store variables	V_m	↑		
		P_{bar}	↑		
	(°F)	T_m	A		1
		V_t	↑		
		V_{tb}	↑		
		N	R/S		2
		V_{soln}	↑		
		V_a	R/S		3
3	a. Compute dry gas meter volume	(V_m)	STO	1	
	(standard conditions)	(P_{bar})	STO	2	
		(T_m)	STO	3	
			B		$V_{m_{std}}$
	b. Compute concentration SO_2	(V_t)	STO	4	
	(standard conditions)	(V_{tb})	STO	5	
		(N)	STO	6	
		(V_{soln})	STO	7	
		(V_a)	STO	8	
		($V_{m_{std}}$)	STO	9	
			C		C_{SO_2}
	c. To convert lb/ft^3 to gm/m^3	lb/ft^3	D		gm/m^3

METHOD 7

DETERMINATION OF NITROGEN OXIDE EMISSIONS FROM STATIONARY SOURCES



As described in Volume 36, No. 247, Part II of the Federal Register, December 23, 1971, the sample volume corrected to standard conditions (528°R, 29.92 inches Hg) is given by:

$$V_{sc} = \left(17.65 \frac{°R}{in.\ Hg}\right)\left(V_f - 25\ ml\right)\left(\frac{P_f}{T_f} - \frac{P_i}{T_i}\right) \qquad (7\text{-}1)$$

where

V_{sc} = sample volume at standard conditions (dry basis), ml
V_f = volume of flask and valve, ml
25 ml = volume of absorbing solution
P_f = final absolute pressure of flask, inches Hg
P_i = initial absolute pressure of flask, inches Hg
T_f = final absolute temperature of flask, °R
T_i = initial absolute temperature of flask, °R

The concentration of NO_x as NO_2 (dry basis) is given by:

$$C = \left(6.2 \times 10^{-5} \frac{lb/SCF}{g/ml}\right)\left(\frac{m}{V_{sc}}\right) \qquad (7\text{-}2)$$

where

C = concentration of NO_x as NO_2 (dry basis), lb/ft^3, standard conditions (i.e., lb/DSCF)
m = mass of NO_2 in gas sample, μgm
V_{sc} = sample volume at standard conditions (dry basis), ml

Note: 1.00 lb/DSCF = 1.602×10^4 gm/DSCM

Example:

V_f = 2,000 ml
P_f = 25.00 inches Hg
T_f = 120°F

P_i = 5.00 inches Hg
T_i = 70°F
m = 5.0 μgm

→ $V_{sc} = 1.17 \times 10^3$ ml
C = 2.64×10^{-7} lb/DSCF
(= 4.23×10^{-3} gm/DSCM)

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	Store variables	V_f	↑		
		P_f	↑		
	(°F)	T_f	A		2
		P_i	↑		
	(°F)	T_i	↑		
		m	R/S		3
3	a. Correct sample volume to dry,	(V_f)	STO	1	
	standard conditions	(P_f)	STO	2	
		(T_f)	STO	3	
		(P_i)	STO	4	
		(T_i)	STO	5	
			B		V_{sc}
	b. Compute concentration of NO_x	(m)	STO	6	
	as NO_2	(V_{sc})	STO	7	
			C		C
	c. To convert lb/DSCF → gm/DSCM	lb/DSCF	D		gm/DSCM

METHOD 8

DETERMINATION OF SULFURIC ACID MIST AND SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

METHOD 8 APol–08
V ACID SO_2 gm/m^3

As described in Volume 36, No. 247 Part II of the Federal Register, December 23, 1971, the dry gas meter volume corrected to standard conditions (528°R, 29.92 inches Hg) is given by:

$$V_{m_{std}} = \left(17.65 \ \frac{°R}{in.\ Hg}\right) V_m \left(\frac{P_{bar} + \frac{\Delta H}{13.6}}{T_m}\right) \qquad (8\text{-}1)$$

where

$V_{m_{std}}$ = volume of gas sample through the dry gas meter, standard conditions, ft^3
V_m = volume of gas sample through the dry gas meter, meter conditions, ft^3
T_m = average dry gas meter temperature, °R
P_{bar} = barometric pressure at the orifice meter, inches Hg
ΔH = pressure drop across the orifice meter, inches H_2O

The concentration of sulfuric acid (standard conditions, dry) is given by:

$$C_{H_2SO_4} = 1.08 \times 10^{-4} \ \frac{lb\text{-}l}{g\text{-}ml} \times (\beta) \qquad (8\text{-}2)$$

where

$C_{H_2SO_4}$ = concentration of sulfuric acid at standard conditions, dry basis, lb/ft^3; (i.e., lb/DSCF)
1.08×10^{-6} = conversion factor including the number of grams per gram equivalent of sulfuric acid (49 g/g-eq.), 458.6 g/lb, and 1,000 ml/l, lb-l/g-ml

β is given by:

$$\beta = \frac{(V_t - V_{tb}) \ N \ \frac{V_{soln}}{V_a}}{V_{m_{std}}}$$

where

V_t = volume of barium perchlorate titrant used for the sample, ml

V_{tb} = volume of barium perchlorate titrant used for the blank, ml

N = normality of barium perchlorate titrant, g-eq./l

V_{soln} = total solution volume of:
- equ. (8-2): sulfuric acid, ml (first impinger and filter)
- equ. (8-3): sulfur dioxide, ml (second and third impingers)

V_a = volume of sample aliquot titrated, ml

$V_{m_{std}}$ = volume of gas sampled through the dry gas meter, standard conditions, ft^3, see equation (8-1)

The concentration of sulfur dioxide (standard conditions, dry) is given by:

$$C_{SO_2} = 7.05 \times 10^{-5} \frac{\text{lb-l}}{\text{g-ml}} \times (\beta) \qquad (8\text{-}3)$$

where

C_{SO_2} = concentration of sulfur dioxide at standard conditions, dry basis, lb/ft^3, (i.e., lb/DSCF)

7.05×10^{-5} = conversion factor including the number of grams per gram equivalent of sulfur dioxide (32 g/g-eq)

Note: $1.00\ lb/ft^3 = 1.602 \times 10^4\ gm/m^3$

Example:

V_m = 100 ft^3

P_{bar} = 29.00 inches Hg

T_m = 100°F

ΔH = 5 inches H_2O

	H_2SO_4	SO_2
V_t =	4 ml	6 ml
V_{tb} =	0.1 ml	0.1 ml
N =	0.005 g-eq/l	0.005 g-eq/l
V_{soln} =	50 ml	75 ml
V_a =	2 ml	2 ml

$\rightarrow V_{m_{std}} = 9.26 \times 10^1\ ft^3$

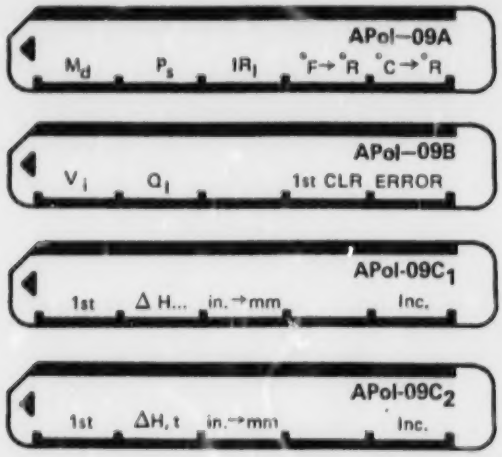
$C_{H_2SO_4} = 5.69 \times 10^{-7}\ lb/ft^3 (= 9.11 \times 10^{-3}\ gm/m^3)$

$C_{SO_2} = 8.43 \times 10^{-7}\ lb/ft^3 (= 1.35 \times 10^{-2}\ gm/m^3)$

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
1	Load program card		[ ] [ ]	
2	Store variables		[RTN] [ ]	
		V_m	[↑] [ ]	
		P_{bar}	[↑] [ ]	
	(°F)	T_m	[↑] [ ]	
		ΔH	[R/S] [ ]	1
		V_t	[↑] [ ]	
		V_{tb}	[↑] [ ]	
		N	[R/S] [ ]	2
		V_{soln}	[↑] [ ]	
		V_a	[R/S] [ ]	3
3	a. Compute dry gas meter volume	(V_m)	[STO] [1]	
	(standard conditions)	(P_{bar})	[STO] [2]	
		(T_m)	[STO] [3]	
		(ΔH)	[STO] [4]	
			[A] [ ]	$V_{m_{std}}$
	b. Compute concentration of H_2SO_4	(V_t)	[STO] [5]	
		(V_{tb})	[STO] [6]	
		(N)	[STO] [7]	
		(V_{soln})	[STO] [8]	
		(V_a)	[STO] [9]	
			[C] [ ]	$C_{H_2SO_4}$
	c. Compute concentration of SO_2	(V_t)	[STO] [5]	
	(change stored variables as	(V_{tb})	[STO] [6]	
	required)	(N)	[STO] [7]	
		(V_{soln})	[STO] [8]	
		(V_a)	[STO] [9]	
			[D] [ ]	C_{SO_2}
4	To convert $lb/ft^3 \rightarrow gm/m^3$	lb/ft^3	[E] [ ]	gm/m^3

SECTION III

CASCADE IMPACTOR OPERATION: PITOT DATA REDUCTION, NOZZLE AND FLOW RATE SELECTION, FLOW METERING PARAMETERS



The following four card routine can be used to determine impactor run data parameters. Card APol-09A is used to compute initial data and an intermediate result IR_1 (for use with card APol-09C). Card APol-09B is used to compute point velocities from pitot data, and the average stack gas velocity over the entire traverse. This is then used to select the correct nozzle for isokinetic sampling. For a low flow rate impactor set up using two calibrated orifices (Figure 9-A), the run parameters (ΔP_{sy}, ΔH, $\Delta H'$) can be calculated with card APol-09C_1 (Example 1). For a high flow rate impactor setup using one calibrated orifice and a gas meter (Figure 9-B), the run parameters (ΔP_{sy}, ΔH, t) can be calculated using card APol-09C_2 (Example 2).

The mean molecular weight, dry (M_d) of flue gas is given by:

$$M_d = 32\ B_{O_2} + 44\ B_{CO_2} + 28(B_{N_2} + B_{CO})$$

where

B_{N_2}, B_{CO}, B_{O_2}, B_{CO_2}, are the dry volumetric fractions for N_2, CO, O_2, and CO_2 respectively

The mean molecular weight, wet, of flue gas, M_s, is given by:

$$M_s = M_d\ (1\text{-}B_{wo}) + 18\ B_{wo}$$

where

B_{wo} = volumetric fraction of water, dimensionless

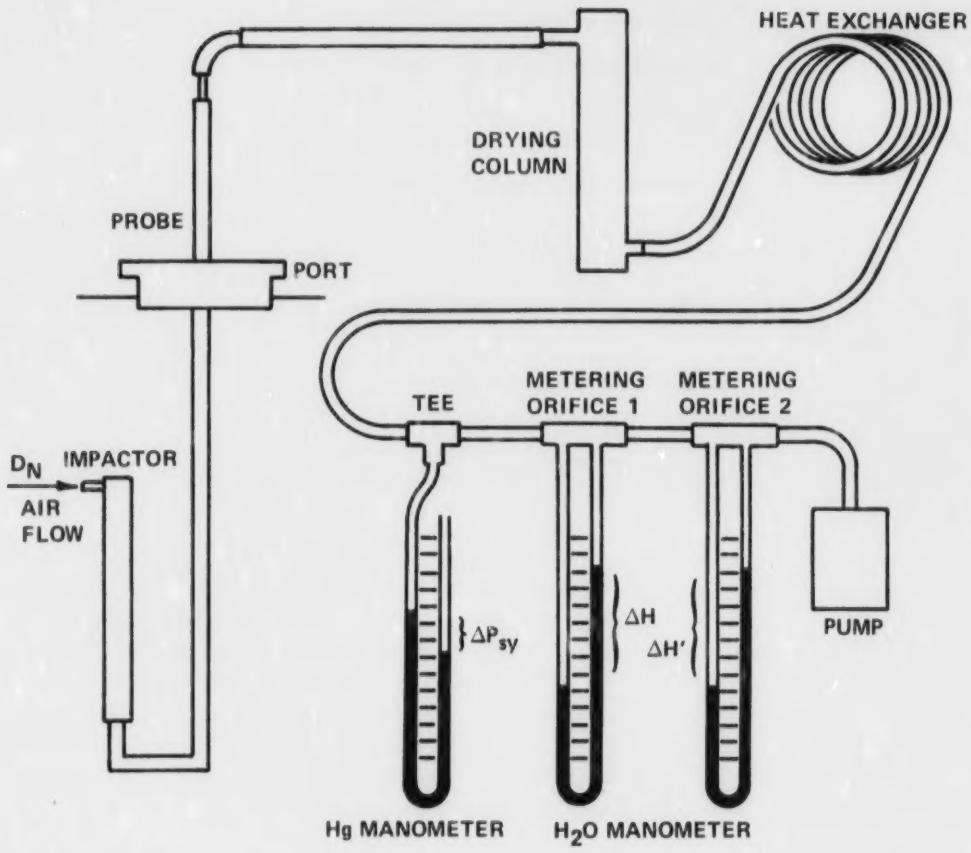


Figure 9-A. A Typical Setup for Low Flow Rate Impactors Using Two Calibrated Orifice Flow Meters

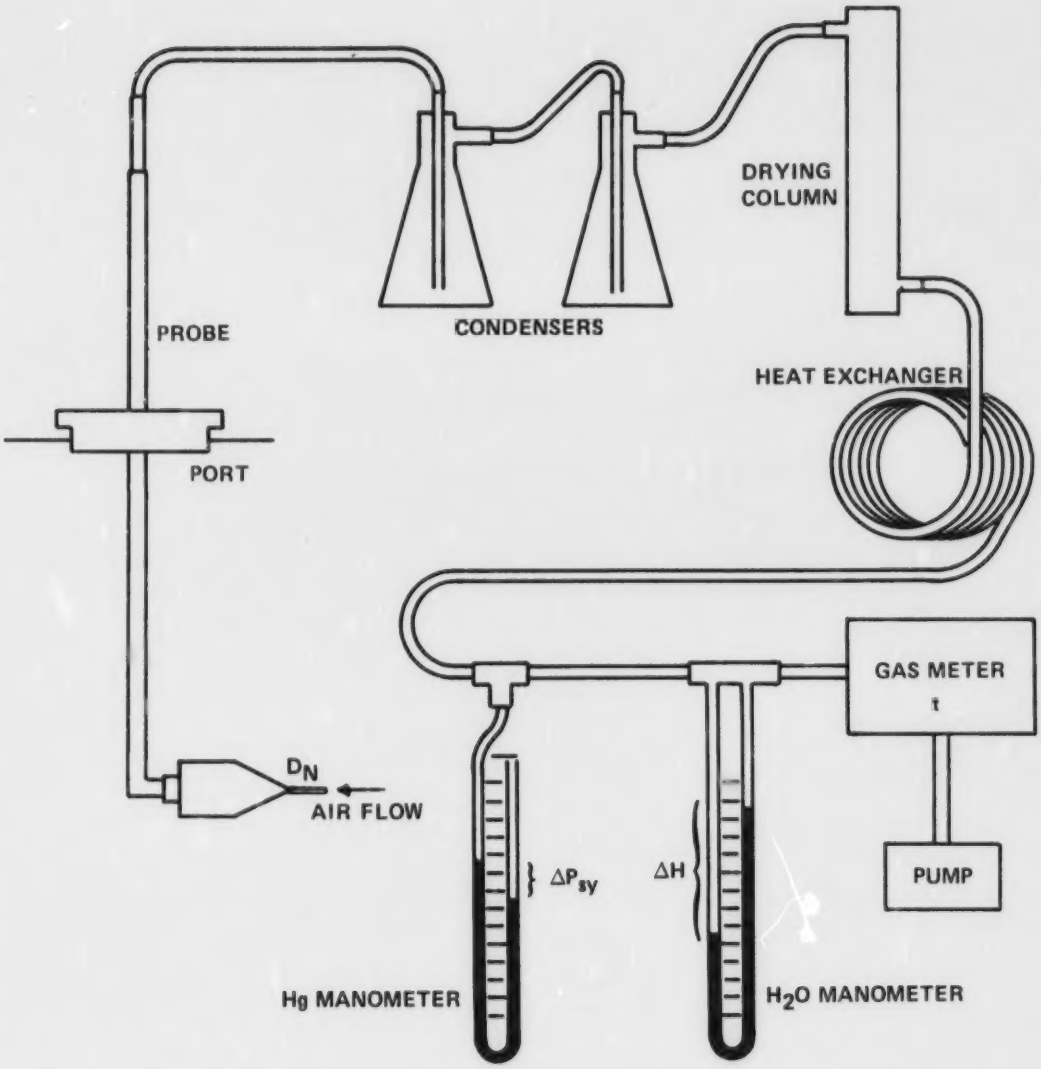


Figure 9-B. A Typical Setup for High Flow Rate Impactors Using a Calibrated Orifice and a Dry Gas Meter

The point velocity (V_i) as determined by a Type S pitot tube is given by:

$$V_i = \theta \sqrt{\Delta p_i \; T_i} \qquad (9\text{-}1)$$

where

Δp_i = velocity pressure (inches H_2O) at point i

T_i = temperature (°R) at point i

θ = pitot-gas composition factor, given by:

$$\theta = 2.9 \, C_p \sqrt{29.92 \frac{R'}{P_s}}$$

where

$$R' = \frac{28.95 \text{ amu}}{M_s}$$

$$P_s = P_{bar} + \left(\frac{\pm \Delta P_s}{13.6} \right)$$

where

P_{bar} = ambient pressure, inches Hg

$\pm \Delta P_s$ = stack pressure differential, inches H_2O

C_p = pitot constant, dimensionless

M_s is as defined above.

Average velocity, $(V_s)_{avg}$, is given by:

$$(V_s)_{avg} = \frac{1}{n} \Sigma \; V_i \; (i = 1,n)$$

Average temperature, $(T_s)_{avg}$, is given by:

$$(T_s)_{avg} = \frac{1}{n} \Sigma \; T_i \; (i = 1,n)$$

The impactor flow rate, Q_I, is given by:

$$Q_I = 5.072 \times 10^{-4} \, (V_s)_{avg} \times D_N^2$$

where

Q_I = impactor flow rate, ft^3/min (i.e., CFM)

$(V_s)_{avg}$ = average velocity, ft/sec

D_N = nozzle diameter, millimeters

The pressure drop across the orifice required to obtain the desired actual impactor flow rate is given by:

$$\Delta H = \frac{\gamma}{P_o \, (Q_{cal})^2} \qquad (9\text{-}2a)$$

where

ΔH = pressure drop across the orifice required to obtain the desired actual impactor flow rate, inches H_2O

Q_{cal} = calibration flow rate (at ΔP_{cal}, T_{cal}, P_{cal}), ACFM

P_o = absolute pressure at the orifice (inches Hg) given by:

$$P_o = P_{bar} - \Delta P_{sy}$$

where

P_{bar} = ambient pressure, inches Hg

ΔP_{sy} = pressure differential to ambient, inches Hg, immediately upstream from the orifice

γ = gas composition, temperature, and pressure constant, given by:

$$\gamma = \left(\frac{Q_I}{(T_s)_{avg}}\right)^2 IR_1 \quad T_o \; c_c$$

where

T_o = orifice temperature, °R

Q_I = desired actual flow rate, ACFM

$(T_s)_{avg}$ = average stack temperature, °R

IR_1 = intermediate value given by:

$$IR_1 = \left[(1-B_{wo}) \; P_s\right]^2 \quad (M_d)$$

where

B_{wo} = volumetric fraction of water

P_s = stack pressure (inches Hg) as used with θ in Equation (9-1)

M_d = mean molecular weight (MMW) of the flue gas, dry

c_c = orifice calibration factor given by:

$$c_c = \frac{T_c \quad \Delta H_c}{P_c \quad M_c} \tag{9-2b}$$

where

T_c = calibration temperature, °R

P_c = calibration pressure, inches Hg

ΔH_c = pressure drop (inches H_2O) for which Q_{cal} is taken

M_c = MMW of the calibration gas, amu

(Note: MMW of standard air is 28.97 amu, dry

c_c = 6.260 for T_c = 535°R, P_c = 29.50 in. Hg, ΔH_c = 10 inches H_2O, and M_c = 28.97)

In any given sampling situation either a gas meter or a second orifice will be used, but not both. A gas meter is the preferred instrument when the required sampling flow rate is within the calibration range of the gas meter. Whenever required flow rates are below the minimum required to actuate the gas meter, a second orifice should be substituted for the gas meter and positioned in series with and immediately downstream of the first orifice. Such is normally the case when sampling at the inlet to a gas cleaning device where high concentrations require the use of low flow rate impactors.

When a second orifice (calibrated at the same conditions as the first orifice (i.e., $c'_c = c_c$)) is used in series with the first orifice, the pressure drop across the second orifice ($\Delta H'$) is given by:

$$\Delta H' = \frac{\gamma}{P_o' \ (Q'_{cal})^2} \qquad (9\text{-}3a)$$

where

$\Delta H'$ = pressure drop across the second orifice, inches H_2O

Q'_{cal} = calibration flow rate for this orifice

γ is as defined for equation (9-2) above, when $c_c = c'_c$.

P_o' = absolute pressure at this orifice (in. Hg), given by:

$$P_o' = P_{bar} - \left(\Delta P_{sy} + \frac{\Delta H}{13.6}\right) \qquad (9\text{-}3b)$$

where

ΔH = pressure drop (in. Hg) across the first orifice

P_{bar} and ΔP_{sy} are as defined for equation (9-2) above.

If a gas meter is used (in place of the second orifice) the time (t, in sec) required for one revolution of the gas meter dial is given by:

$$t = \frac{K}{Q_m} \qquad (9\text{-}4)$$

where

$K = V_o \times 60$ sec/min

V_o = volume for one revolution, ft^3

Q_m = actual flowrate through the gas meter, ft^3/min, actual (i.e., ACFM), given by:

$$Q_m = Q'_{cal} \sqrt{\frac{\Delta H'}{P'_o}\left(\frac{T_o}{c'_c \ M_d}\right)}$$

where

$\Delta H'$ = pressure drop across the imaginary second orifice (Q_m equals $Q'_{orifice}$) as determined by setting $Q'_{cal} = Q_{cal}$ and $c'_c = c_c$ where c_c and P'_o are given by equations (9-2b) and (9-3b) respectively.

(For Q_m in CFM and V_o = 0.1 ft^3, t in seconds is given by $t = 6/Q_m$)

Note:
- On all three cards program steps are arranged so that R/S can frequently be used rather than a letter address, A, B, C, D, E. The operator can decide which sequence is best suited to his needs.
- Both orifices must have the same calibration factor (i.e., $c'_c = c_c$).
- This program assumes specific values for c_c and K. When these values are not appropriate, new values should be calculated using equations (9-2b) and (9-4) and the appropriate value for c_c and K entered as program steps in place of the assumed values 6.260 and 6 respectively.
- 1.00 inch = 25.40 mm
- 1 gm/gm-mole = 1 lb/lb-mole = 1 amu

Example No. 1:

(ΔP_{sy}, ΔH, $\Delta H'$) - - Two Orifices

1. Load Card APol-09A.

2a. $B_{O_2} = 0.05$, $B_{N_2} = 0.78$, $B_{CO_2} = 0.15$, $B_{CO} = 0.02$ → $M_d = 30.60$ amu

2b. $B_{wo} = 0.06$ → $M_s = 29.84$ amu

2c. $P_{bar} = 29.43$ in. Hg, $\Delta P_s = -6.7$ in. H_2O → $P_s = 28.94$ in. Hg.

2d. → $IR_1 = 2.264 \times 10^4$

2e. $T_o = 75°F + 460 = 535°R$

3. Load Card APol-09B

4. $C_p = 0.83$

5. $(\Delta p_1, T_1) = (0.06$ in. H_2O, $321°F)$ → $V_1 = 16.50$ ft/sec, n = 1

$(\Delta p_2, T_2) = (0.08$ in. H_2O, $329°F)$ → $V_2 = 19.15$ ft/sec, n = 2

$(\Delta p_3, T_3) = (0.08$ in. H_2O, $330°F)$ → $V_3 = 19.16$ ft/sec, n = 3

$(\Delta p_4, T_4) = (0.07$ in. H_2O, $325°F)$ → $V_4 = 17.87$ ft/sec, n = 4

6a. $D_N = 1.5$ mm → $Q_I = 0.0207$ ft³/min

$D_N = 2.0$ mm → $Q_I = 0.0369$ ft³/min

6b. $(V_s)_{avg} = 18.17$ ft/sec

6c. $(T_s)_{avg} = 786.3°R$

7. Load Card APol-09C_1

Note: $c_c = 6.26$, K is used with APol-09C_2 only and thus may not have any value.

8. Q_{cal} = 0.02363 ft^3/min (c_c = 6.260 for 10 in. H_2O, 29.50 in. Hg, 535°F, 28.97 amu)
   Q'_{cal} = 0.02509 ft^3/min (c'_c = 6.260 for 10 in. H_2O, 29.50 in. Hg, 535°F, 28.97 amu)
   T_o = 535°R
   IR_1 = 2.264 x 10^4
   P_{bar} = 29.43 in. Hg
   M_d = 30.60
9. ΔP_{sy} = 1.5 in. Hg → ΔH = 10.7 in H_2O, $\Delta H'$ = 9.7 in. H_2O
10. "E"

ΔP_{sy} = 2.0 in. Hg, ΔH	= 10.9 in. H_2O, $\Delta H'$	= 9.9 in. H_2O
2.5 in. Hg	11.1 in. H_2O	10.1 in. H_2O
3.0 in. Hg	11.3 in. H_2O	10.3 in. H_2O
3.5 in. Hg	11.5 in. H_2O	10.5 in. H_2O

Example No. 2:

(ΔP_{sy}, ΔH, t) - - Orifice and Gas Meter

1. Load Card APol-09A
2a. B_{O_2} = 0.05, B_{N_2} = 0.78, B_{CO_2} = 0.15, B_{CO} = 0.02 → M_d = 30.60 amu
2b. B_{wo} = 0.06 → M_s = 29.84 amu
2c. P_{bar} = 29.43 in. Hg, ΔP_s = -6.7 in. H_2O → P_s = 28.94 in. Hg
2d. → IR_1 = 2.264 x 10^4
2e. T_o = 75°F + 460 = 535°R
3. Load Card APol-09B
4. C_p = 0.83
5. (Δp_1, T_1) = (0.06 in. H_2O, 321°F) → V_1 = 16.50 ft/sec, n = 1
   (Δp_2, T_2) = (0.08 in. H_2O, 329°F) → V_2 = 19.15 ft/sec, n = 2
   (Δp_3, T_3) = (0.08 in. H_2O, 330°F) → V_3 = 19.16 ft/sec, n = 3
   (Δp_4, T_4) = (0.07 in. H_2O, 325°F) → V_4 = 17.87 ft/sec, n = 4
6a. D_N = 3.18 mm Q_I = 0.0932 ft^3/min
   D_N = 7.94 mm Q_I = 0.5808 ft^3/min
6b. → $(V_s)_{avg}$ = 18.17 ft/sec
6c. → $(T_s)_{avg}$ = 786.3°R
7. Load Card APol-09C_2
   Note: c_c = 6.26, K = 6.00

8. Q_{cal} = 0.3512 ft^3/min (c_c = 6.260 for 10 in. H_2O, 29.50 in. Hg. 535°F, 28.97 amu)

STO 2

T_o = 535°R

IR_1 = 2.264 x 10^4

P_{bar} = 29.43 in. Hg

M_d = 30.60

9. ΔP_{sy}= 1.5 in. Hg ΔH = 12.0 in. H_2O, t = 15.1 sec

10. "E"

ΔP_{sy} =	2.0 in. Hg,	ΔH = 12.2 in. H_2O, t =	14.8 sec)
	2.5 in. Hg	12.5 in. H_2O	14.5 sec
	3.0 in. Hg	12.7 in. H_2O	14.2 sec
	3.5 in. Hg	12.9 in. H_2O	13.9 sec

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
1	Load program card APol-09A		[ ] [ ]	
2	Compute initial data		[ ] [ ]	
	a. Compute M_d	B_{O_2}	[STO] [4]	
		B_{N_2}	[STO] [7]	
		B_{CO_2}	[STO] [8]	
		B_{CO}	[STO] [+]	
			[7] [A]	M_d
	b. Compute M_s	B_{wo}	[R/S] [ ]	M_s
	c. Compute P_s	P_{bar}	[↑] [ ]	
		$\pm\Delta P_s$	[B] [ ]	P_s
	d. Compute ΔH parameter IR_1		[C] [ ]	IR_1
	for use with APol-09C		[ ] [ ]	
	e. To convert temperatures		[ ] [ ]	
	°F → °R	°F	[D] [ ]	°R
	°C → °R	°C	[E] [ ]	°R
3	Load program card APol-09B		[ ] [ ]	
4	Store variables and	C_p	[STO] [1]	
	initialize	(P_s)	[STO] [2]	
		$(\sqrt{P_s \cdot M_s})$	[STO] [3]	
			[D] [ ]	0.00

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
5	a. Load pitot data (Δp_i, T_i):			
	(in. H_2O)	Δp_i	↑	
	(in °F)	T_i	A	V_i
	b. Optional: for display of Δp_i and			
	T_i to determine correct entry.		R/S	Δp_i
	(If after recalling Δp_i and T_i, the		R/S	T_i
	operator determines that a wrong			
	value was entered, this entry may			
	be eliminated by pressing "E"			
	Program E takes the point			
	velocity previously calculated			
	with the erroneous data and			
	subtracts it from the summation reg-			
	ister. It also corrects the summation			
	registers for T_s and n.			
	c. Optional: for display of the index			
	counter, n		R/S	n
6	Compute Q_I:			
	a. After all pitot traverse data has			
	been loaded, select a nozzle and			
	compute the corresponding Q_I			
	required for isokinetic sampling.			
	Repeat as necessary with different	D_N	B	Q_I
	choices for D_N to obtain an			
	acceptable Q_I			
	b. Display $(V_s)_{avg}$ (fps)		R/S	$(V_s)_{avg}$
	c. Display $(T_s)_{avg}$ (°R)		R/S	$(T_s)_{avg}$
7	a. Load card APol-09C_1 for			
	(ΔP_{sv}, ΔH, $\Delta H'$) sets			
	or			
	Load card APol-09C_2 for			
	(ΔP_{sv}, ΔH, t) sets			

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
	b. Enter, as program steps, the correct			
	value for c_s and K from equations			
	(9-2b) and (9-4) respectively.			
	c. Proceed to the appropriate set of			
	instructions.			

For (ΔP_{sy}, ΔH, $\Delta H'$) Sets; Two Orifices

APol-09C$_1$

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
8	Initialize			
	a. Store preliminary data	Q_{cal}	STO 1	
		Q'_{cal}	STO 2	
	(°R)	T_o	STO 4	
	(from APol-09A)	IR_1	STO 5	
		P_{bar}	STO 6	
		$((T_s)_{avg})$	STO 7	
		(Q_1)	STO 8	
		M_d	STO 9	
	b. Initialize		A	0.00
9	Compute (ΔP_{sy}, ΔH, $\Delta H'$)	ΔP_{sy}	B	ΔH
	given ΔP_{sy}		R/S	$\Delta H'$
10	To increment previous		E	ΔP_{sy}
	ΔP_{sy} by steps of		R/S	ΔH
	+0.5 in. Hg		R/S	$\Delta H'$
11	To convert from inches → mm	inches	C	mm

For (ΔP_{sy}, ΔH, t) Sets; Orifice and Gas Meter

APOL-09C$_2$

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
8	Initialize		[ ] [ ]	
	a. Store preliminary data	Q_{cal}	STO 1	
			STO 2	
	($^\circ$R)	T_o	STO 4	
	(from APol-09A)	IR_1	STO 5	
		P_{bar}	STO 6	
		$((T_s)_{avg})$	STO 7	
		(Q_l)	STO 8	
		M_d	STO 9	
	b. Initialize		A [ ]	0.00
9	Compute (ΔP_{sy}, ΔH, t)	ΔP_{sy}	B [ ]	ΔH
	given ΔP_{sy}		R/S [ ]	t
10	To increment previous ΔP_{sy} by steps		E [ ]	ΔP_{sy}
	of		R/S [ ]	ΔH
	+0.5 in. Hg		R/S [ ]	t
11	To convert from inches → mm	inches	C [ ]	mm

CASCADE IMPACTOR OPERATION

Velocity Traverse - Inlet/outlet (Circle One)

Plant: _____ Date: ____ ____ ____

Location: _____ Time (circle one) AM / PM

POINT VELOCITIES

Port Number

Traverse Point No.	1	2	3	4	5	6	7	8
(Top) 1								
2								
3								
4								
5								
(Bottom) 6								

Depth = _____

B_{O_2} = _____

B_{N_2} = _____

B_{CO_2} = _____

B_{CO} = _____ → M_d = _____

B_{wo} = _____ → M_s = _____

P_{bar} = _____ in. Hg

$\pm\Delta P_s$ = _____ in. H_2O → P_s = _____ in. Hg

→ IR_1 = _____

T_o = _____ °F +460 = _____ °R

C_p = _____ ; D_N = _____ mm → Q_I = _____ CFM

$(V_s)_{avg}$ = _____ fps

$(T_s)_{avg}$ = _____ °R

INCHES		INCHES		MM
1/8	=	.125	=	3.18
3/16	=	.1875	=	4.76
1/4	=	.250	=	6.35
5/16	=	.3125	=	7.94
3/8	=	.375	=	9.53
1/2	=	.500	=	12.70

ΔP_{sy} (in. Hg)	No. 1 ΔH (in. H_2O)	t or No. 2 $\Delta H'$ (in. H_2O)

Orifice No. 1

ID:

Q_{cal}: _____

Orifice No. 2

Q'_{cal}: _____

(c_c = ; k = program steps)

Pitot Traverse Data; Velocity Pressures and Temperatures:

(1) C_p = _____ (2) P_s = _____ (3) $\sqrt{M_s \cdot P_s}$ = _____

	Port 1		Port 2		Port 3		Port 4		Port 5		Port 6		Port 7		Port 8	
	Δp	T	Δp	T	Δp	T	Δp	T	Δp	T	Δp	T	Δp	T	Δp	T
1																
2																
3																
4																
5																
6																

. . . . . .

Fold Here

The above format should be positioned upside down on the reverse side of the data form so that when the paper is folded along the dotted line the calculated values for the point velocities may be easily entered in the table.

IMPACTOR FLOW RATE GIVEN ORIFICE ΔH

The actual flow rate through an impactor, Q_I, is given by:

$$Q_I = \frac{Q_{cal}\, T_s}{(1-B_{wo})P_s} \sqrt{\frac{(P_{bar} - \Delta P_{sy})\ \Delta H}{T_o\, M_d\, c_c}} \qquad (10\text{-}1)$$

where

T_s = stack temperature, °R

B_{wo} = volumetric fraction of water

P_{bar} = ambient pressure, in. Hg

ΔP_{sy} = ambient to system pressure differential at a point immediately upstream of the orifice, in. Hg

ΔH = pressure drop across the orifice, in. H_2O

T_o = orifice temperature, °R

c_c = orifice calibration factor given by:

$$c_c = \frac{T_c\ \Delta H_c}{P_c\ M_c} \qquad (10\text{-}2)$$

where

P_c = calibration pressure, in. Hg

T_c = calibration temperature, °R

ΔH_c = pressure drop across the orifice, in. Hg, (at temperature T_c and pressure P_c) when the calibration flow rate Q_c is measured

M_c = mean molecular weight of the calibration gas

Q_{cal} = calibration flow rate for a pressure drop ΔH_c (at conditions T_c and P_c), ft^3/min, actual (i.e., ACFM)

P_s = stack pressure, in. Hg, given by:

$$P_s = P_{bar} + \Delta P_s/13.6$$

where

ΔP_s = pressure differential, ambient to stack, inches H_2O

P_{bar} = ambient pressure, inches Hg

M_d = dry mean molecular weight of the flue gas as given by:

$$M_d = 32\, B_{O_2} + 44\, B_{CO_2} + 28(B_{N_2} + B_{CO})$$

where B_{N_2}, B_{O_2}, B_{CO_2}, and B_{CO} are the dry volumetric fractions for N_2, O_2, CO_2, and CO respectively.

Example:

Program Steps:

$c_c = 6.260$ (for P_c = 29.50 in. Hg, T_c = 535°R ΔH_c = 10 in. H_2O, M_c = 28.97)

Data:

$B_{O_2} = 0.06$
$B_{CO_2} = 0.13$
$B_{N_2} = 0.78$
$B_{CO} = 0.03$

→ M_d = 30.32 lb/lb-mole

P_{bar} = 28.04 in. Hg
ΔP_s = -6.0 in. H_2O

→ P_s = 27.6 in. Hg

Q_{cal} = 0.420 CFM, T_o = 45°F, T_s = 380°F, B_{wo} = 0.12

ΔH = 6.0 in. H_2O
ΔP_{sy} = 2.0 in. Hg

→ Q_I = 0.586 ACFM (stack conditions)
(= 16.6 ALPM, stack conditions)

ΔH = 6.5 in. H_2O
ΔP_{sy} = 4.0 in. Hg

→ Q_I = 0.587 ACFM (stack conditions)
(= 16.6 ALPM, stack conditions)

Q_{cal} = 0.0494 CFM
ΔH = 1.4 in. H_2O
ΔP_{sy} = 2.0 in. Hg

→ Q_I = 0.0333 ACFM (stack conditions)
(= 0.944 ALPM, stack conditions)

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	a. Load program card				
	b. Enter correct value of c_c [from				
	equation (10-2)] as program				
	steps.				
2	Compute M_d	B_{O_2}	↑		
		B_{CO_2}	↑		
		B_{N_2}	↑		
		B_{CO}	E		M_d
3	Compute stack pressure	P_{bar}	STO	6	
	(Note: Use + for positive pressure,				
	− for negative)	$\pm \Delta P_s$	D		P_s
4	a. Store variables	Q_{cal}	STO	1	
	(°F)	T_o	STO	2	
	(°F)	T_s	STO	3	
		B_{wo}	STO	4	
		(P_s)	STO	5	
		(P_{bar})	STO	6	
		(M_d)	STO	7	
	b. Compute impactor flow rate	ΔH	↑		
		ΔP_{sy}	A		Q_I
5	For a second set (ΔH, ΔP_{sy}) using				
	the same orifice, repeat Line 4b				
	above.				
6	For a second set (ΔH, ΔP_{sy}) using				
	a different orifice, same c_c, store				
	the new Q_c in register No. 1 then				
	go to Line 4b above.				
7	To convert from CFM → LPM	CFM	C		LPM

IMPACTOR FLOW RATE GIVEN GAS VELOCITY AND NOZZLE DIAMETER

For isokinetic sampling, when the average flue gas velocity (or point velocity if a single point sample is taken) over a traverse path is known, the actual flow rate through an impactor (Q_I) corresponding to a given choice of nozzle diameter, D_N, is given by:

$$Q_I = 5.072 \times 10^{-4} (V_s)_{avg} (D_N)^2 \qquad (11\text{-}1)$$

where

Q_I = actual flow rate through the impactor, ft^3/min (i.e., ACFM)

$(V_s)_{avg}$ = average flue gas velocity, feet per second

D_N = nozzle diameter, millimeters

For Q_I in cm^3/sec:

$$Q_I = 0.2394 \, (V_s)_{avg} (D_N)^2 \qquad (11\text{-}2)$$

For Q_I in liters per minute (LPM):

$$Q_I = 0.01436 \, (V_s)_{avg} (D_N)^2 \qquad (11\text{-}3)$$

(All Q_I are for actual temperature and pressure)

Note:
- 1/4 inch = 6.35 mm
- 3/8 inch = 9.53 mm
- 1/2 inch = 12.7 mm
- 1.00 inch = 25.4 mm
- 1.00 mm = 0.0394 inch

Example:

$(V_s)_{avg}$ = 60 ft/sec
D_N = 2 mm

→ Q_I = 0.1217 ACFM
Q_I = 57.46 cm^3/sec, actual
Q_I = 3.446 ALPM

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
1	Load program card		[ ] [ ]	
2	Store variables (ft/sec)	$(V_s)_{avg}$	[STO] [1]	
	(mm)	D_N	[STO] [2]	
3	To compute Q_I in ACFM		[A] [ ]	Q_I
4	To compute Q_I in cm^3/sec, actual		[B] [ ]	Q_I
5	To compute Q_I in ALPM		[C] [ ]	Q_I

IMPACTOR SAMPLING TIME TO COLLECT 50 MILLIGRAMS

The approximate time (t_g) required to collect 50 mg of sample for a mass loading in units of grains per actual cubic feet is given by:

$$t_g = \frac{0.77162}{(Q_I)\,(G)} \qquad (12\text{-}1)$$

where

t_g = collection time, minutes
Q_I = actual impactor flow rate, ACFM
G = mass loading, gr/ACF

If the mass loading is given in units of milligrams per actual cubic meter, the approximate time is given by:

$$t'_g = \frac{1765.7}{(Q_I)\,(G')} \qquad (12\text{-}2)$$

where

Q_I = actual impactor flow rate, ACFM
G' = mass loading, mg/ACM

Note:
- 1.00 lb = 7,000 grains
- 1.00 lb = 453.6 grams

Example:

For mass loading in units of gr/ACF:

G = 2 gr/ACF & Q_I = 0.03 ACFM → t_g = 0.1251
(i.e., 12 min, 51 sec)
(w/opt. R/S: 12.86 minutes)

G = 0.006 gr/ACF & Q_I = 0.5 ACFM → t_g = 4.1712
(i.e., 4 hours, 17 min, 12 sec)
(w/opt. R/S: 257.2 minutes)

For mass loading in units of mg/ACM:

$$G' = 13 \text{ mg/ACM} \;\&\; Q_I = 0.5 \text{ ACFM} \rightarrow t'_g = 4.3139$$

(i.e., 4 hours, 31 min., 39 sec)
(w/opt. R/S: 271.6 minutes)

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	Compute t_g, given the grain loading				
	a. Store variables	G	STO	3	
	(ACFM)	Q_I	STO	8	
	b. Compute t_g		A		t_g
	(Note: Output is in the format				
	HH.MMSS; i.e., hours, minutes,				
	seconds. Insert optional R/S for				
	output in decimal minutes.)				
3	Compute t'_g, given the mg loading				
	a. Store variables	G'	STO	3	
	(ACFM)	Q_I	STO	8	
	b. Compute t'_g		C		t'_g
	(Note: same output format as 2b.)				
4	Convert lbs → grains	lbs	E		gr

IMPACTOR FLOW RATE, SAMPLE VOLUME, MASS LOADING

The average flow rate through the gas meter (Q_m), meter conditions is given by:

$$Q_m = V_m/t$$

where

Q_m = average flow rate through the gas meter, meter conditions, ft^3/min, (i.e., ACFM)

V_m = measured volume, ft^3

t = run time, minutes

The average actual flow rate through the impactor, $(Q_I)_{avg}$, stack conditions, is given by:

$$(Q_I)_{avg} = Q_m \left[\frac{(P_{bar} - \Delta P_m)}{P_s}\right]\left[\frac{T_s}{T_m\ (1 - B_{wo})}\right] \qquad (13\text{-}1)$$

where

$(Q_I)_{avg}$ = average actual flow rate through the impactor, as determined by the gas meter measurement, stack conditions, ft^3/min

P_{bar} = ambient pressure, absolute, in. Hg

P_s = stack pressure, absolute given by $P_s = P_{bar} + \Delta P_s/13.6$ where ΔP_s is the stack to ambient pressure differential, in. H_2O

T_s = temperature of the stack gas, absolute, °R

T_m = temperature of the metered gas, °R

B_{wo} = volumetric fraction of water, dimensionless

ΔP_m = meter to ambient pressure differential, in. Hg, at the inlet to the gas meter given by:

$$\Delta P_m = \Delta P_{sy} + (\Delta H/13.6)$$

where

ΔP_{sy} = ambient to system pressure differential at a point immediately upstream of the orifice, inches Hg

ΔH = pressure drop across the orifice, inches H_2O

(Note: The above equation for ΔP_m is for an equipment set-up such that the gas meter is immediately downstream from the orifice.)

Correspondingly, the actual volume, $(V_I)_{avg}$ through the impactor (sample volume) at stack conditions is given by:

$$(V_I)_{avg} = (Q_I)_{avg} \times t \qquad (13.2)$$

where

$(V_I)_{avg}$ = average actual volume through the impactor, stack conditions, ft^3

t = run time, minutes

$(Q_I)_{avg}$ is defined by equation (13-1).

This impactor sample volume corrected to normal conditions (68°F, 29.92 in. Hg) is given by:

$$V_N = (V_I)_{avg} \left[17.65 \frac{P_s}{T_s} (1 - B_{wo})\right] \qquad (13\text{-}3)$$

where

V_N = $(V_I)_{avg}$ corrected to normal conditions, dry, ft^3

$(V_I)_{avg}$, P_s, T_s, and B_{wo} are as defined above.

Thus the Mass Loading (G_N), normal conditions, is given by:

$$G_N = (0.01543)\ M_s/V_N \qquad (13\text{-}4)$$

where

G_N = mass loading, normal conditions, dry, grains/ft^3 (i.e., gr/DNCF)

M_s = mass collected on a given stage when stage loadings are desired; or M_s is the total mass collected for all stages (plus backup filter) when the total mass loading is desired, grains

V_N is as defined above.

This same mass loading expressed in terms of stack conditions (wet) is given by:

$$G_A = (0.01543)\ M_s/(V_I)_{avg} \qquad (13\text{-}5)$$

where

G_A = mass loading, stack conditions, wet, grains/actual ft^3 (i.e., gr/ACF)

$(V_I)_{avg}$ and M_s are as defined above.

Note: 1 gr/ft^3 = 2.288 gm/m^3

Example:

B_{wo} = 0.05
T_s = 300°F
P_{bar} = 30.00 in. Hg
ΔP_s = - 13.6 in. H_2O } → P_s = 29.00 in. Hg
T_m = 70°F

t = 20 min
V_m = 10 ft^3
ΔP_{sy} = 1.6 in. Hg
ΔH = 5.4 in. H_2O

→ Q_m = 0.50 ACFM (meter conditions)
$(Q_I)_{avg}$ = 0.73 ACFM (stack conditions)
$(V_I)_{avg}$ = 14.58 ACF (stack conditions)
V_N = 9.33 DNCF (normal/standard conditions)

For Stage One: M_1 = 25 mg → Stage One Mass Loadings are:
G_N = 0.041 gr/DNCF (= 0.095 gm/DNCM)
G_A = 0.026 gr/ACF (= 0.061 gm/ACM)

For Total Stage weight:

M_T = 100 mg → Total Mass Loading is:
G_N = 0.17 gr/DNCF (= 0.379 gm/DNCM)
G_A = 0.11 gr/ACF (= 0.242 gm/ACM)

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	Store variables	B_{wo}	STO	1	
	(°F)	T_s	STO	2	
	($P_s = P_{bar} \pm \Delta P_s/13.6$)	P_s	STO	3	
	(°F)	T_m	STO	4	
		P_{bar}	STO	5	
3	Load variables and compute				
	a. Load variables and compute				
	Q's and V's	t	↑		
		V_m	↑		
		ΔP_{sys}	↑		
		ΔH	A		Q_m
			R/S		$(Q_I)_{avg}$
			R/S		$(V_I)_{avg}$
			R/S		V_N
	b. Compute mass loading	M_s	C		G_N
			R/S		G_A
4	a. To convert $gr/ft^3 \rightarrow gm/m^3$	gr/ft^3	↑		
		2.288	X		gm/m^3
	b. To convert in. H_2O to in. Hg	in. H_2O	E		in. Hg

IMPACTOR STAGE D_{50}

For a given geometry, the impactor stage D_{50} cutpoints are determined by the conditions at which the impactor is run. The stage D_{50}'s can be calculated by an iterative solution of the following two equations (14-1) and (14-2):

$$\#S{:}D_{50_i} = K_S \sqrt{\frac{\mu \, P_S}{(Q \; \rho_p \, P_A) \, C_{i-1}}} \qquad (14\text{-}1)$$

where

$\#S{:}D_{50_i}$ = the ith iteration for the D_{50} for Stage #S, cm

K_S = the stage constant, a function of geometry, (see also Tables (14-1) through (14-5) and equations (14-5)and (14-6))

P_S = local absolute pressure downstream of the stage jet, inches Hg

Q = impactor flow rate, cm^3/sec

P_A = absolute pressure at impactor inlet, inches Hg

ρ_p = particle density, gm/cm^3

μ = gas viscosity, gm/cm-sec given by:*

$$\mu = (174.4 + 0.406\ T) \times 10^{-6}$$

where

T = gas temperature, °C

C_{i-1} = slip correction factor, i–1 iteration

An initial guess, C_o, is used for D_{50_1}; subsequent C_i, using D_{50_i}, are given by:

$$C_i = 1 + \frac{2L}{D_{50_i}} \left[1.23 + 0.41 \text{ EXP } \left(-.44 \frac{D_{50_i}}{L}\right) \right] \qquad (14\text{-}2)$$

where

D_{50_i} = $\#S{:}D_{50_i}$ given by equation (14-1) using the previously calculated value for C_{i-1} (for $i \neq 1$ and C_o for $i = 1$)

L = mean free path of the gas, cm, given by:*

$$L = 1.04 \frac{\mu}{P_S} \sqrt{1 + 0.00367T} \qquad (14\text{-}3)$$

where

μ, P_S, and T are the same as in equation (14-1) and T has units of °C.

* For Standard Air only, 0° to 410°C; maximum error, 2%.

An initial value, C_o, is chosen for use in equation (14-1) for i = 1 then subsequent calculations for D_{50i} use C_{i-1}. A closeness criterion is used to determine when D_{50i} has adequately approached the D_{50}. This criterion is satisfied when:

$$\left| 1 - \frac{C_{i-1}}{C_i} \right| \leq 0.001 \qquad (14\text{-}4)$$

The impactor stage constant K_s is a function of geometry. For round holes, K_{sRO} is given by:

$$K_{sRO} = \sqrt{\Psi_{50_s}} \left(\frac{18\pi \, D_s^3 \, X_s}{4} \right)^{1/2} \qquad (14\text{-}5)$$

where

$\sqrt{\Psi_{50_s}}$ = square root of the Stokes number at 50% collection efficiency (theoretical, or from calibration data), for stage s, dimensionless[1]

X_s = number of jets per stage

D_s = jet diameter, cm

The impactor stage constant for rectangular slits is given by:

$$K_{sRT} = \sqrt{\Psi_{50_s}} \, (18 \, w^2 L)^{1/2} \qquad (14\text{-}6)$$

where

$\sqrt{\Psi_{50_s}}$ = square root of the Stokes number at 50% collection efficiency (theoretical, or from calibration data) for stage s, dimensionless

w = width of slit

L = total length of slit or slits on stage s

Note:

- Tables 14-1 through 14-5 give tabulated typical stage constants, K_s, for five commercially available cascade impactors. These values were obtained by using equation (14-5), or (14-6) and the calibration values of $\sqrt{\Psi_{50_s}}$ for each stage. When a different geometry is used the value for $\sqrt{\Psi_{50_s}}$ should be recalibrated for the new geometry.
- 1.00 μm = 10^{-4} cm
- Aerodynamic diameter stage cut point as defined by the Task Group on Lung Dynamics[2] is calculated by setting the particle density in equation 14-1 equal to unity
- Impaction aerodynamic diameter stage cut points as defined by Mercer and Stafford[3] are calculated by setting the slip correction factor and particle density both equal to unity in equation 14-1. Calculation of these diameters cannot be made using this program (APol-14).

Reference: 1. Cushing, K. M., G. E. Lacey, J. D. McCain, and W. B. Smith. Particle Sizing Techniques for Control Device Evaluation. Environmental Protection Agency. Southern Research Institute. Washington, D. C. Environmental Protection Tech. Series No. EPA-600/2-76-280. 1976. p. 94.

2. Task Group on Lung Dynamics, "Deposition and Retention Models for Internal Dosemetry of the Human Respiratory Tract", Health Physics, Vol. 12. 1966. pp. 173-203.

3. Mercer, T.T., Stafford, R.G. "Impaction from Round Jets". Ann. Occupational Hygiene. Vol. 12. 1969. pp. 41-48.

Example No. 1: Using Standard Air as the carrier gas;
(μ and L are automatically calculated)

174.4

0.406

$T = 22°C$ 1

$Q = 236\ cm^3/sec$

$P_A = 30.00$ in. Hg

$\rho_p = 1.35\ gm/cm^3$ 2

For Stage 1:

0.00367

$K_1 = 1.208$

$P_2 = 30.00$ in. Hg → #1:$D_{50} = 9.08 \times 10^{-4}$ cm

For Stage 2:

0.00367

$K_2 = 1.074$

$P_2 = 30.00$ in. Hg → #2:$D_{50} = 8.07 \times 10^{-4}$ cm

⋮

For Stage 8:

0.00367

$K_8 = 0.0544$

$P_8 = 28.50$ in. Hg → #8:$D_{50} = 3.23 \times 10^{-5}$ cm

Using Standard Air as the carrier gas: (μ and L are automatically calculated)

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
1	Load program card			
2	a. Store variables	174.4	↑	
		0.406	↑	
		T	A	1
		Q	↑	
		P_A	↑	
		ρ_p	R/S	2
	b. Compute Stage D_{50}	0.00367	↑	
	(Do s = 1 → N for N stages)	K_s	↑	
		P_s	E	#S:D_{50}

Example No. 2: Using carrier gases other than Standard Air:
(μ and L are entered manually)

$L = 3.40 \times 10^{-6}$ cm

$\mu = 9.15 \times 10^{-5}$ gm/sec-cm

$Q = 236$ cm^3/sec

$P_A = 30$ in. Hg

$\rho_p = 1.35$ gm/cm^3

For Stage 1:

1.5

$K_1 = 1.208$

$P_1 = 30.00$ in Hg → $\#1{:}D_{50} = 6.43 \times 10^{-4}$ cm

For Stage 2:

1.5

$K_2 = 1.074$

$P_2 = 30.00$ in Hg → $\#2{:}D_{50} = 5.71 \times 10^{-4}$ cm

...

For Stage 8:

1.5

$K_8 = 0.0544$

$P_8 = 28.50$ in. Hg → $\#8{:}\ D_{50} = 2.45 \times 10^{-5}$ cm

Using carrier gases other than Standard Air: (μ and L are entered manually)

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	a. Store variables				
	(cm)	L	STO	1	
		μ	STO	3	
		Q	↑		
		P_A	×		
		ρ_p	×		
			STO	5	
	b. Compute Stage D_{50}	1.5	STO	2	
		K_s	STO	8	
		P_s	STO	4	
			GTO	9	
	(Do s = 1 → N for N Stages)		R/S		#S:D_{50}

Andersen Mark III Stack Sampler

Andersen 2000, Inc.

Atlanta, Georgia 30320

Stage No.	No. of Jets	Jet Diameter (cm)	$\sqrt{\Psi_{50}}$	K_S
1	264	.1638	.311	1.26
2	264	.1253	.431	1.165
3	264	.0948	.411	0.731
4	264	.0759	.391	0.498
5	264	.0567	.330	0.272
6	264	.0359	.370	0.154
7	264	.0261	.330	0.0850
8	156	.0251	.280	0.0523

Table 14-1

Modified Brink Model BMS-11 Cascade Impactor
Monsanto Enviro-Chem Systems, Inc.
St. Louis, Missouri 63166

Stage No.	No. of Jets	Jet Diameter (cm)	$\sqrt{\Psi_{50}}$ Glass Fiber	K_s Glass Fiber	$\sqrt{\Psi_{50}}$ Grease	K_s Grease
0	1	.360	.30	.244	.32	.260
1	1	.244	.32	.145	.35	.159
2	1	.176	.27	.0750	.38	.106
3	1	.138	.29	.0559	.34	.0655
4	1	.093	.38	.0405	.26	.0277
5	1	.073	.41	.0304	.33	.0245
6	1	.057	.27	.0138	.27	.0138

Table 14-2

University of Washington Source Test Cascade Impactor
Pollution Control Systems, Inc.
Renton, Washington 98055

Stage No.	No. of Jets	Jet Diameter (cm)	$\sqrt{\Psi_{50}}$	K_s
1	1	1.824	.12	1.11
2	6	.577	.31	1.25
3	12	.250	.29	0.472
4	90	.0808	.21	0.172
5	110	.0524	.37	0.175
6	110	.0333	.35	0.0839
7	90	.0245	.30	0.0410

Table 14-3

MRI Model 1502 Inertial Cascade Impactor
Meterology Research, Inc.
Altadena, California 91001

Stage No.	No. of Jets	Jet Diameter (cm)	$\sqrt{\Psi_{so}}$	K_s
1	8	.870	.11	0.949
2	12	.476	.25	1.07
3	24	.205	.35	0.598
4	24	.118	.34	0.254
5	24	.084	.29	0.130
6	24	.052	.35	0.0764
7	12	.052	.40	0.0618

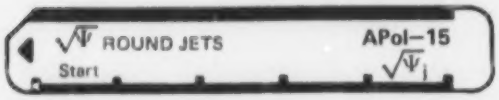
Table 14-4

Sierra Model 226 Source Sampler
Sierra Instruments, Inc.
Carmel Valley, California 93924

Stage No.	Jet Slit Width (cm)	Jet Slit Length (cm)	$\sqrt{\Psi_{so}}$	K_s
1	.359	5.156	.33	1.14
2	.199	5.152	.42	0.805
3	.115	3.882	.65	0.625
4	.063	3.844	.49	0.257
5	.036	3.869	.42	0.126
6	.029	2.301	.43	0.0803

Table 14-5

$\sqrt{\Psi}$ CALCULATION - ROUND JETS



The square root of the Stokes number, $\sqrt{\Psi}$, for an impactor stage is a function of geometry and particle size. For a round hole geometry, this number is given by:

$$\sqrt{\Psi_j} = D_{p_j} \sqrt{\frac{7.07 \times 10^{-2} \ (Q \ \rho_p \ P_A) \ C_j}{\mu P_s \ (D_c^3 X)}} \qquad (15\text{-}1)$$

where

$\sqrt{\Psi_j}$ = square root of the Stokes number for this stage for a particle having diameter D_{p_j}, dimensionless

D_{p_j} = particle diameter (note: spherical particles are assumed), cm

P_s = local absolute pressure downstream of the stage jet, inches Hg

Q = impactor flow rate, cm^3/sec

P_A = absolute pressure at impactor inlet, inches Hg

ρ_p = particle density, gm/cm^3

D_c = jet diameter, cm

X = number of jets for this stage

7.07×10^{-2} = $4/18\pi$, a constant

μ = gas viscosity, gm/sec-cm, given by:*

$$\mu = (174.4 + 0.406 \ T) \times 10^{-6}$$

where

T = gas temperature, °C

C_j = slip correction factor for this particle diameter is given by:

$$C_j = 1 + \frac{2L}{D_{p_j}} \left[1.23 + 0.41 \ \text{EXP} \ (-.44 \ \frac{D_{p_j}}{L}) \right] \qquad (15\text{-}2)$$

where

D_{p_j} = particle diameter, cm

L = mean free path of the gas, cm, given by:*

$$L = 1.04 \ \frac{\mu}{P_s} \ \sqrt{1 + 0.00367T} \qquad (15\text{-}3)$$

where

μ, P_s, and T are the same as in equation (15-1) and T has units of °C.

* For Standard Air only, 0° to 410°C; maximum error, 2%.

Reference:
- Ranz, W. E., and J. B. Wong, "Impaction of Dust and Smoke Particles." Ind. Eng. Chem., 44:1371-1381, June 1952.
- Cushing, K. M., G. E. Lacey, J. D. McCain, and W. B. Smith. Particulate Sizing Techniques for Control Device Evaluation. Environmental Protection Agency. Southern Research Institute. Washington, D. C. Environmental Protection Tech. Series No. EPA-600/2-76-280. 1976. 94p.

Example No. 1: Using Standard Air as the carrier gas:
(μ and L are automatically calculated)

$X = 264$ holes

$D_c = 0.0353$ cm

$P_s = 29.00$ in. Hg 1

174.4

0.406

$T = 20°C$ 2

$Q = 236\ cm^3/sec$

$P_A = 30.00$ in. Hg

$\rho_p = 1.35\ gm/cm^3$ 3

$D_{p_1} = 1\ \mu m \rightarrow \sqrt{\Psi_1} = 0.358$, dimensionless

$D_{p_2} = 5\ \mu m \rightarrow \sqrt{\Psi_2} = 1.69$, dimensionless

Using Standard Air as the carrier gas: (μ and L are automatically calculated)

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
1	Load program card			
2	a. Store variables and compute $\sqrt{\Psi_1}$	X	↑	
		D_c	↑	
		P_s	A	1
		174.4	↑	
		0.406	↑	
		T	R/S	2
		Q	↑	
		P_A	↑	
		ρ_p	R/S	3
	b. Compute $\sqrt{\Psi_j}$ (μm)	D_{p_j}	E	$\sqrt{\Psi_j}$
	(Do j = 1, N for N different particle			
	diameters)			

Example No. 2: Using carrier gases other than Standard Air:
(μ and L are entered manually)

μ = 9.15×10^{-5} gm/sec-cm
L = 3.40×10^{-6} cm

Q = 236 cm^3/sec
P_A = 30.00 in. Hg
ρ_p = 1.35 gm/cm^3

X = 264 holes
D_c = 0.0353 cm
P_s = 29.0 in. Hg 1

D_{p_1} = 1 μm
.0001
RCL 4 → $\sqrt{\Psi_1}$ = 0.487, dimensionless

D_{p_2} = 4 μm
.0001
RCL 4 → $\sqrt{\Psi_2}$ = 1.89, dimensionless

Using carrier gases other than Standard Air: (μ and L are entered manually)

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
1	Load program card			
2	a. Store variables	μ	STO 6	
		L	STO 4	
		Q	↑	
		P_A	X	
		ρ_p	X	
			STO 5	
		X	↑	
		D_c	↑	
		P_s	A	1
	b. Compute $\sqrt{\Psi_j}$ (μm)	D_{p_j}	↑	
		.0001	X	
			STO 1	
	(Do j = 1, N for N different		RCL 4	L
	particle diameters)		C	$\sqrt{\Psi_j}$

$\sqrt{\Psi}$ CALCULATION - RECTANGULAR SLOTS

The square root of the Stokes number, $\sqrt{\Psi}$, for an impactor stage is a function of geometry and particle size. For a rectangular slot geometry, this number is given by:

$$\sqrt{\Psi_j} = D_{p_j} \sqrt{\frac{0.0556\ (Q\ \rho p\ P_A)\ C_j}{\mu P_s\ (w^2 \ell)}} \qquad (16\text{-}1)$$

where

$\sqrt{\Psi_j}$ = square root of the Stokes number for this stage for a particle with diameter D_{p_j}, dimensionless

D_{p_j} = particle diameter (note: spherical particles are assumed), cm

P_s = local absolute pressure downstream of the stage jet, inches Hg

Q = impactor flow rate, cm^3/sec

ρ_p = particle density, gm/cm^3

P_A = absolute pressure at impactor inlet, inches Hg

w = width of the slot

ℓ = total slot length

0.0556 = 1/18, a constant

μ = gas viscosity, gm/cm-sec, given by:*

$$\mu = (174.4 + 0.406\ T) \times 10^{-6}$$

where

T = gas temperature, °C

C_j = slip correction factor for this particle diameter as given by:

$$C_j = 1 + \frac{2L}{D_{p_j}} \left[1.23 + 0.41\ \mathrm{EXP}\ \left(-.44\ \frac{D_{p_j}}{L}\right) \right] \qquad (16\text{-}2)$$

where

D_{p_j} = particle diameter, cm

L = mean free path of the gas, cm, given by:*

$$L = 1.04\ \frac{\mu}{P_s} \sqrt{1 + 0.00367\ T} \qquad (16\text{-}3)$$

where

μ, P_s, and T are the same as in equation (16-1), and T has units of °C

* For Standard Air only, 0° to 410°C; maximum error, 2%.

Reference:
- Ranz, W. E. and J. B. Wong. "Impaction of Dust and Smoke Particles." Ind. Eng. Chem., 44:1371-1381, June 1952.
- Cushing, K. M., G. E. Lacey, J. D. McCain, and W. B. Smith. Particulate Sizing Techniques for Control Device Evaluation. Environmental Protection Agency. Southern Research Institute. Washington, D. C. Environmental Protection Tech. Series No. EPA-600/2-76-280. 1976. 94 p.

Example No. 1: Using Standard Air as the carrier gas:
(μ and L are automatically calculated)

ℓ = 3.912 cm
w = 0.036 cm
P_s = 29.0 in. Hg 1

174.4
0.406
T = 20°C 2

Q = 236 cm^3/sec
P_A = 30.00 in. Hg
ρ_p = 1.35 gm/cm^3 3

D_{p_1} = 1 μm → $\sqrt{\Psi_1}$ = 0.481, dimensionless

D_{p_2} = 5 μm → $\sqrt{\Psi_2}$ = 2.26, dimensionless

Using Standard Air as the carrier gas: (μ and L are automatically calculated)

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
1	Load program card			
2	a. Store variables and compute $\sqrt{\Psi_1}$	ℓ	↑	
		w	↑	
		P_s	A	1
		174.4	↑	
		0.406	↑	
		T	R/S	2
		Q	↑	
		P_A	↑	
		ρ_p	R/S	3
	b. Compute $\sqrt{\Psi_j}$ (μm)	D_{p_j}	E	$\sqrt{\Psi_j}$
	(Do j = 1 → N for N different			
	particle diameters)			

Example No. 2: Using carrier gases other than Standard Air:
(μ and L are entered manually)

μ = 9.15 x 10^{-5} gm/sec-cm
L = 3.40 x 10^{-6} cm

Q = 236 cm^3/sec
P_A = 30.00 in. Hg
ρ_p = 1.35 gm/cm^3

ℓ = 3.912 cm
w = 0.036 cm
P_s = 29.0 in. Hg 1

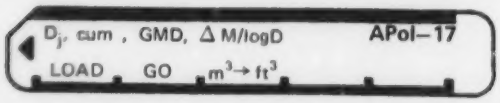
D_{p_1} = 1 μm
.0001
RCL 4 → $\sqrt{\Psi_1}$ = 0.654, dimensionless

D_{p_2} = 4 μm
.0001
RCL 4 → $\sqrt{\Psi_2}$ = 2.54, dimensionless

Using carrier gases other than Standard Air: (μ and L are entered manually)

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
1	Load program card		[ ] [ ]	
2	a. Store variables	μ	STO 6	
		L	STO 4	
		Q	↑ [ ]	
		P_A	X [ ]	
		ρ_p	X [ ]	
			STO 5	
		ℓ	↑ [ ]	
		w	↑ [ ]	
		P_s	A [ ]	1
	b. Compute $\sqrt{\Psi_j}$ (μm)	D_{p_j}	↑ [ ]	
		.0001	X [ ]	
			STO 1	
	(Do j = 1, N for N different		RCL 4	L
	particle diameters)		C [ ]	$\sqrt{\Psi_j}$

CUMULATIVE CONCENTRATION vs. D_{50} AND $\Delta M/\Delta \log D$ vs. GEOMETRIC MEAN DIAMETER



The cumulative concentration for stage index number i ($c_{i,cum}$) is defined to be the sum of the concentrations for all stages having a D_{50} smaller than the D_{50} for stage index number i. Thus for an impactor having a cyclone, six stages, and a backup filter (where the stage index numbers are assigned such that the D_{50}'s are decreasing for increasing index numbers, i.e., $D_{i+1} < D_i$) the cumulative concentration for stage index number five ($c_{5,cum}$) is the sum of the concentrations for stage index numbers eight, seven, and six (i.e., $c_8 + c_7 + c_6$). This is expressed by the following:

$$c_{j,cum} = \sum_{i = N \rightarrow j-1} c_i \qquad (17\text{-}1)$$

where

$c_{j,cum}$ = cumulative concentration of all particles having diameter smaller than the D_{50} for stage index number j

c_i = mass concentration (mass per unit volume) for stage index number i

N = total number of stage index numbers where stage number N has the smallest D_{50}

A cumulative concentration curve plots cumulative concentration against the D_{50} for the index number (i.e., $c_{j,cum}$ vs. D_j).

The differential of a cumulative mass curve is given by:

$$(\Delta M/\Delta \log D)_i = \frac{c_i}{\log(D_{i-1}) - \log(D_i)} \qquad (17\text{-}2)$$

where

$(\Delta M/\Delta \log D)_i$ = differential of the cumulative mass curve for the size band (D_{i-1}, D_i)

D_i = D_{50} for stage index number i

D_{i-1} = D_{50} for stage index number i-1 ($D_{i-1} > D_i$)

c_i = mass concentration for stage index number i, given by:

$$c_i = m_i/V_T \qquad (17\text{-}3)$$

where

m_i = stage weight for stage index number i

V_T = total volume of gas sampled through the impactor, as given in APol-13

Choice of units for V_T (i.e., stack conditions, wet; engineering standard conditions, dry; etc.) and m_i (i.e., mg, grams, grains, etc.) determine the units for $(\Delta M/\Delta \log D)_i$ and $c_{i,cum}$ (i.e., mg/ACM, mg/DSCM, etc.).

The geometric mean diameter, GMD_i, is given by:

$$GMD_i = \sqrt{D_i \times D_{i-1}} \qquad (17\text{-}4)$$

A $\Delta M/\Delta \log D$ curve plots $(\Delta M/\Delta \log D)_i$ against GMD_i.

NOTE:
- Choice of units for V_T and m_i determine the units of $(\Delta M/\Delta \log D)_i$ and $c_{i,cum}$
- By convention, a minimum diameter for the filter catch is usually assigned a value of one half that of the D_{50} for the last stage of the impactor.
- For i = 1, D_{i-1} is taken to be the maximum particle diameter as determined by microscopic examination of the particles collected on the first stage (or cyclone when used).
- 1.00 lb = 7,000 grains
- 1.00 gm = 2.505×10^{-3} lbs
- 1.00 m^3 = 10^3 liters = 35.31 ft^3
- 1.00 mg/m^3 = 4.371×10^{-2} gr/ft^3 = 6.242×10^{-8} lb/ft^3

EXAMPLE:

For a six stage impactor, with cyclone, D_{50}'s and stage weights are as follow:

STAGE ID	INDEX No.	D_{50} (μm)	STAGE WEIGHT (mg)
	0	55*	
Cyclone	1	9.00	1.13
SO	2	6.60	0.63
S1	3	3.73	0.21
S2	4	2.20	0.20
S3	5	1.52	0.49
S4	6	0.79	3.38
S5	7	0.55	2.04
Filter	8	0.28**	0.45

* maximum particle diameter $V_T = 0.40$ ft^3, dry, standard conditions

** by convention; $D_{50} = \frac{1}{2} D_7$

1. Load Card

2. Store variables:

V_T = 0.40 DSCF (from equation (13-2))
N = 8
D_8 = 0.28 μm
m_8 = 0.45 mg

("A" converts V_T to m^3 for use in step 3)

3. For Stage Index No. 8 (i.e., Filter):

0.000 STO 7
D_7 = 0.55 μm
m_7 = 2.04 mg

"B" → i = 8
D_8 = 0.28 μm
$c_{8,cum}$ = 0.00 mg/DSCM
GMD_8 = 0.39 μm
$(\Delta M/\Delta \log D)_8$ = 1.35×10^2 mg/DSCM

For Stage Index No. 7:
D_6 = 0.79 μm
m_6 = 3.38 mg

"B" → i = 7
D_7 = 0.55 μm
$c_{7,cum}$ = 3.97×10^1 mg/DSCM
GMD_7 = 0.66 μm
$(\Delta M/\Delta \log D)_7$ = 1.15×10^3 mg/DSCM

⋮

For Stage Index No. 1:

D_O = 55 μm
m_O = 55***

"B" → i = 1
D_1 = 9.00 μm
$c_{1,cum}$ = 6.53×10^2 mg/DSCM
GMD_1 = 22.25 μm
$(\Delta M/\Delta \log D)_1$ = 1.27×10^2 mg/DSCM

*** The value used for m_O is arbitrary since this entry is only used to position the stack so that D_O will be correctly stored.

For Stage Index No. 0:

$D_o = 0.00$
$m_o = 0.00$

"B" → $i = 0$
$D_o = 55\ \mu m$
$c_{o,\ cum} = 7.53 \times 10^2$

Tabulated Results

Stage ID	Index No.	Size (μm)	Cum. Conc. (mg/DSCM)	GMD (μm)	$\Delta M/\Delta \log D$ (mg/DSCM)
	0	55	7.53×10^2		
Cyclone	1	9.00	6.53×10^2	22.25	1.27×10^2
S0	2	6.60	5.98×10^2	7.71	4.13×10^2
S1	3	3.73	5.79×10^2	4.96	7.48×10^1
S2	4	2.20	5.61×10^2	2.86	7.70×10^1
S3	5	1.52	5.18×10^2	1.83	2.69×10^2
S4	6	0.79	2.20×10^2	1.10	1.05×10^3
S5	7	0.55	3.97×10^1	0.66	1.15×10^3
Filter	8	0.28*	—	0.39*	1.35×10^2*

* values are somewhat arbitrary and may not be meaningful.

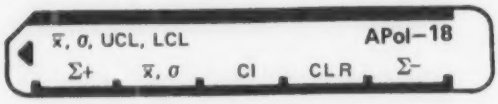
4,5,6 unit conversions:

$0.40\ ft^3 = 1.13 \times 10^{-2}\ m^3$
$5.50\ mg/DSCM = 2.40\ gr/DSCF$
$(= 3.43 \times 10^{-4}\ lb/DSCF)$

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	Store variables				
	(DSCF)	V_T	↑		
		N	↑		
	(μm)	D_N	↑		
	(mg)	m_N	A		0.00
3	Compute values for Stage Index No. i				
	a. Initalize	(V_T)	STO	1	
	(For arbitrary input units, do not	(N)	STO	2	
	use Line 2, store manually.	(D_N)	STO	3	
	Input units fix out put units.)	(m_N)	STO	4	
		0.00	STO	7	
	b. Compute	D_{i-1}	↑		
		m_{i-1}	B		i
			R/S		D_i
			R/S		$c_{i,cum}$
			R/S		GMD_i
			R/S		$(\Delta M/\Delta \log D)_i$
	Do i = N → 0, decreasing				
4	$ft^3 \rightarrow m^3$	ft^3	C		m^3
5	$mg/m^3 \rightarrow gr/ft^3$	mg/m^3	RCL	8	
			X		gr/ft^3
6	$mg/m^3 \rightarrow ft^3$	mg/m^3	RCL	9	
			X		lb/ft^3

SECTION IV

MEAN, STD. DEVIATION, 90/95% CONFIDENCE INTERVALS, MEAN ± CI



The mean ($\bar{x}$) for a set of N numbers, $\{x_i\}$, is given by:

$$\bar{x} = \frac{(\Sigma\ x_i)}{N} \tag{18-1}$$

The standard deviation (σ) for this set of numbers is given by:

$$\sigma = \sqrt{\lambda/(N-1)} \tag{18-2}$$

where

$$\lambda = (\Sigma x_i^2) - N(\bar{x})^2$$

The relative standard deviation is given by:

$$RSD = \sigma/\bar{x} \tag{18-3}$$

The 90% (or 95%, depending on our choice of c_1, c_2, & c_3) confidence interval (CI) is approximated by:

$$\begin{aligned} CI &= T(\sigma/\sqrt{N}) \\ &= \left[c_1 + c_2\,(N-1)^{c_3}\right]\ (\sigma/\sqrt{N}) \end{aligned} \tag{18-4}$$

where

c_1, c_2, and c_3 are constants for $N \geq 3$:

For the 90% CI; $c_1 = 1.645$, $c_2 = 2.605$, $c_3 = -1.186$

For the 95% CI; $c_1 = 1.960$, $c_2 = 5.550$, $c_3 = -1.346$

The lower confidence limit (LCL) is given by:

$$LCL = \bar{x} - CI$$

The upper confidence limit (UCL) is given by:

$$UCL = \bar{x} + CI$$

Note: • Units are determined by the choice of units for $\{x_i\}$

• For N = 2 or 3, T has the following value:

90% CI: N = 2, T = 6.314; N = 3, T = 2.920

95% CI: N = 2, T = 12.71; N = 3, T = 4.303

Reference: Dixon, W. J., and F. J. Massey, Jr. Introduction to Statistical Analysis. Second ed. New York, McGraw-Hill, 1957. p. 127, 128, 384.

Example:

Given the following set of 4 numbers:

$$\left.\begin{array}{l} x_1 = 0.395 \\ x_2 = 0.384 \\ x_3 = 0.383 \\ x_4 = 0.385 \end{array}\right\} \rightarrow \begin{array}{l} N = 4 \\ \bar{x} = 3.87 \times 10^{-1} \\ \sigma = 5.56 \times 10^{-3} \\ \sigma/\bar{x} = 1.44 \times 10^{-2} \text{ (i.e., 1.44\%)} \end{array}$$

For 90% CI:

$$\begin{array}{l} CI = 6.54 \times 10^{-3} \\ LCL = 3.80 \times 10^{-1} \\ UCL = 3.93 \times 10^{-1} \end{array}$$

For 95% CI:

$$\begin{array}{l} CI = 8.97 \times 10^{-3} \\ LCL = 3.78 \times 10^{-1} \\ UCL = 3.96 \times 10^{-1} \end{array}$$

If x_1 (i.e., $x_1 = 0.395$) is eliminated from the set; N = 3

$$\begin{array}{l} \bar{x} = 3.84 \times 10^{-1} \\ \sigma = 1.00 \times 10^{-3} \\ \sigma/\bar{x} = 2.60 \times 10^{-3} \text{ (i.e., 0.260\%)} \\ 95\% \text{ CI} = 2.39 \times 10^{-3} \end{array}$$

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	Initialize		D		0.00
3	Load constants				
	a. For 90% confidence interval	1.645	STO	1	
		2.605	STO	2	
		-1.186	STO	3	
	or				
	b. For 95% confidence interval	1.960	STO	1	
		5.550	STO	2	
		-1.346	STO	3	
4	Enter data Points x_i; i = 1, N	x_i	A		i
5	(to correct for erroneous x_i)	x_i	E		i
6	a. Compute the mean		B		$\bar{x}$
	b. Compute the standard deviation		R/S		σ
	c. Compute the relative standard dev.		R/S		$\sigma/\bar{x}$
	d. Compute the confidence interval		C		CI
	e. Compute the lower confidence limit		R/S		LCL
	f. Compute the upper confidence limit		R/S		UCL
7	To determine the effect of omitting a				
	point x_j from the data set:	x_j	E		N'
	then proceed to Line 6 above.				
8	For a new data set, clear $\Sigma+$ registers,		D		0.00
	then proceed to Line 4 above.				

RESISTIVITY AND ELECTRIC FIELD STRENGTH

For a point plane resistivity probe, the resistivity, (ρ) of a layer of fly ash collected on the probe is given by:

$$\rho = \frac{V}{I}\frac{A}{L} \qquad (19\text{-}1)$$

where

V = voltage across the layer of fly ash, volts
I = current through the layer of fly ash, amps
A = area of the layer of fly ash, cm^2
L = thickness of the layer of fly ash, cm

The electric field strength (E) is given by:

$$E = \frac{V}{L} \qquad (19\text{-}2)$$

Example:

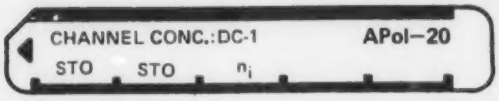
A = 5.00 cm^2
L = 0.100 cm

V = 1,000 volts
I = 0.00100 amps

→ $\rho = 5.00 \times 10^7$ ohm-cm
E = 1×10^4 volts/cm

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
1	Load program card		[ ] [ ]	
2	Store variables	A	[STO] [1]	
		L	[STO] [2]	
3	a. Load stack and compute ρ and E	V	[↑] [ ]	
		I	[A] [ ]	ρ
	b. Compute E		[R/S] [ ]	E
4	To calculate E only	V	[↑] [ ]	
		L	[E] [ ]	E

CHANNEL CONCENTRATIONS FOR THE KLD DROPLET MEASURING DEVICE (1-600 μm), DC-1



As described in EPA-650/2-75-018, Environmental Protection Technology Series, "Design, Development, and Field Test of A Droplet Measuring Device," the droplet concentration, n_i for each of the six channels is given by the following:

$$n_i = \frac{N_i}{V\ t\ \ell\ (2D_i + d)} \quad (i = 1,6) \tag{20-1}$$

where

n_i = droplet concentration for the ith channel, droplets/cm^3
N_i = total number of droplets counted in the ith channel
V = flow velocity, cm/sec
t = time interval, sec
ℓ = sensor length, cm
D_i = average droplet diameter for the ith channel, cm
d = sensor wire diameter, 5×10^{-4} cm

Example:

Channel No. 1

$D_1 = 1.40 \times 10^{-4}$ cm
$N_1 = 505$

$t = 130$ sec
$V = 311$ cm/sec

$\ell = 0.10$ cm
$d = 5 \times 10^{-4}$ cm

A, B, R/S, C → n_1 = 160 droplets/cm^3

Channel No. 2

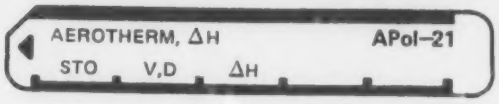
$D_2 = 2.15 \times 10^{-4}$ cm
$N_2 = 290$

A, C → n_2 = 77 droplets/cm^3

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	a. Store channel variables	D_i	↑		
		N_i	A		1
	b. (sec)	t	↑		
		V	B		2
		ℓ	↑		
		d	R/S		3
3	Compute channel concentration, n_i	(D_i)	STO	1	
	(Do i = 1,6)	(N_i)	STO	2	
		(t)	STO	3	
		(V)	STO	4	
		(ℓ)	STO	5	
		(d)	STO	6	
			C		n_i
	(Note: For successive channels, Line 2b				
	can be eliminated)				

AEROTHERM HIGH VOLUME STACK SAMPLER

STACK VELOCITY, NOZZLE DIAMETER, ISOKINETIC ΔH



As detailed in the operation manual for the Aerotherm High Volume Stack Sampler, the stack velocity (as given by the Type S pitot) is given by:

$$V_s = K' \; C_p \sqrt{\frac{\Delta p \, T_s}{M_s}} \qquad (21\text{-}1)$$

where

V_s = point velocity of stack gas, m/sec

C_p = pitot tube coefficient, dimensionless

Δp = velocity head of the stack gas for the pitot at this point, (pitot Δp), cm H_2O

T_s = absolute stack gas temperature at this point, °K

M_s = molecular weight of stack gas (wet basis), gm/gm-mole

K' = an intermediate value, given by:

$$K' = 34.96 \frac{m}{sec} \left(\frac{gm}{gm\text{-}mole\text{-}°K} \right)^{1/2} (P_s)^{-1/2} \qquad (21\text{-}2)$$

where

P_s = pressure of the stack gas, absolute, cm Hg

For P_s = 75 cm Hg (29.53 inches Hg), K' has the value 4.037

When the velocity is known and a desired flow rate chosen, the appropriate nozzle can be selected from the following:

$$D_N = 0.461 \sqrt{\frac{T_s \; Q_m}{V_s \; B_d \; T_m \; (P_s/P_m)}} \qquad (21\text{-}3)$$

where

D_N = correct nozzle diameter for obtaining the desired isokinetic flow rate, cm

$$0.461 = \left[\left(\frac{4}{\pi}\right) \frac{10^4}{60 \times 10^3} \right]^{1/2} cm \left(\frac{m/sec}{l/min} \right)^{1/2}$$

Q_m = the desired flow rate, meter conditions, l/min

T_m = absolute meter temperature, °K

P_s/P_m = ratio of absolute stack pressure and absolute pressure at the meter

B_d = dry gas fraction given by:

$$B_d = (1-B_{wo})$$

where

B_{wo} = proportion by volume of water vapor in the stack gas (Method 4, equation (4-3))

T_s and V_s are as given in equation (21-1) above.

The next smaller available nozzle size should be used in the particular sampling application.

The correct pressure drop, ΔH_i, for isokinetic sampling is given by:

$$\Delta H_i = \frac{T_m \ \Delta p_i}{T_s} \left[\frac{(D_N')^2 \ C_p \ B_d}{JD_o^2}\right]^2 \left[\frac{(P_s/P_m) \ M_d}{M_s}\right] \qquad (21\text{-}4)$$

where

ΔH_i = required velocity head across the orifice, cm H_2O, to obtain isokinetic sampling with the given nozzle diameter, D_N', at traverse point i

Δp_i = velocity head of the stack gas for the pitot at traverse point i, cm H_2O

D_N' = diameter of the nozzle selected, cm

JD_o^2 = orifice constant given by:

$$JD_o^2 = (J) \ (D_o)^2$$

where

J = orifice constant, dimensionless

D_o = diameter of sharp edged orifice, cm

M_d = dry molecular weight of the flue gas (Method 3, equation (3-2)), gm/gm-mole

T_m, (P_s/P_m), B_d, M_s, T_s, C_p, and V_s are as defined for equation (21-1 and (21-3) above.

PROCEDURE

Step 1 Select all traverse points on the duct to be sampled. Let N be the total number of points selected.

Step 2 Obtain pitot data for each of these N points $\{(\Delta p_i, T_i); i = 1,N)\}$

Step 3 Using the extremes from this set, select a nozzle, D_N', using equation (21-3). In selecting the desired meter flow rate, Q_m, be sure that adequate pump capacity will be available for maintaining isokinetic sampling when the pressure drop across the filter increases as the filter loads up.

Step 4 Using D_N' and the extremes of the data set $\{(\Delta p_i, T_i); i = 1,N)\}$, select one orifice (from among those available) for which good ΔH_i values (greater than 1.27 cm) can be obtained at all traverse points.

Step 5 Having selected D_N' and one orifice (JD_O^2), obtain the run data, (ΔH_i, Δp_i), for each traverse point by using equation (21-4).

Note:
- This program assumes that the stack pressure (P_S) is 75.0 cm Hg and uses the corresponding value for K' as program steps. For stack pressures greatly different from 75.0 cm Hg, K' should be recalculated from equation (21-2) and the corresponding value entered as program steps in place of the assumed value 4.037.
- 1.00 inch = 2.540 cm
- 1.00 foot = 0.3048 m

Example:

Given the following set of traverse data, select a nozzle diameter and orifice, then calculate (ΔH_i, Δp_i) run data:

Port	Data	Traverse Point 1	2	3	4	5	6
A	Δp_i(cmH_2O)	9.50	10.15	9.75	9.60	9.45	9.25
	T_{S_i}(°C)	147	149	147	146	146	145
B	Δp_i(cmH_2O)	9.65	9.85	9.75	9.70	9.45	9.30
	T_{S_i}(°C)	146	148	147	147	147	145

Available nozzles: 1/4 inch (0.6350 cm); 3/8 inch (0.9525 cm); 1/2 inch (1.270 cm); 9/16 inch (1.429 cm); 5/8 inch (1.588 cm)

Available orifices:

$J_1 = 0.690$	$J_2 = 0.770$	$J_3 = 1.00$
$D_1 = 0.480$ cm	$D_2 = 0.716$ cm	$D_3 = 0.905$
$(JD_O^2)_1 = 0.159$ cm²	$(JD_O^2)_2 = 0.395$ cm²	$(JD_O^2)_3 = 0.819$ cm²

Selecting D_N' Based on Maximum V_s:

Max T_{s_k} = 149°C
$(JD_o^2)_1$ = 0.159 cm² (first guess)
P_s/P_m = 0.9993; (P_s = 75.95 cm Hg, P_m = 76.00 cm Hg; using K' = 4.037)
C_p = 0.85

B_d = 0.80
M_d = 29.00 gm/gm-mole
T_m = 37.8°C
M_s = 26.80 gm/gm-mole

Max Δp_k = 10.15 cm H_2O

→ Max $V_s = 4.34 \times 10^1$ m/sec

Q_m = 113 l/min

→ $D_N = 9.67 \times 10^{-1}$ cm

Thus we would select D_N' = 0.9525 cm (STO 3)

Selecting JD_o^2 For Best ΔH, Given D_N':

For Maximum ΔH:

$(JD_o^2)_1$ = (already stored in No. 2)

T_{s_k} = (already stored in No. 8)

Max Δp_k = 10.15 cm H_2O

"C" → $\Delta H_k = 1.22 \times 10^2$ cm H_2O

ΔH is too high thus we will try a different orifice, $(JD_o^2)_3$

$(JD_o^2)_3$ = 0.819 cm²(STO 2)
T_{s_k} = (already stored in No. 8)
Max Δp_k = 10.15 cm H_2O

"C" → ΔH_k = 4.59 cm H_2O

For minimum ΔH:

$(JD_o^2)_3 =$ (already stored in No. 2)

$T_{s_j} = 145°C$ ("A")

min $\Delta p_j = 9.25$ cm H_2O

"C" $\rightarrow \Delta H_j = 4.22$ cm H_2O

Thus we would select $(JD_o^2)_3$ as our orifice.

Computing Run Data:

For Port A:

$T_{s_1} = 147°C$ ("A")

$\Delta p_1 = 9.50$ cm H_2O

"C" $\rightarrow \Delta H_1 = 4.31$ cm H_2O

$T_{s_2} = 149°C$ (R/S)

$\Delta p_2 = 10.15$ cm H_2O

R/S $\rightarrow \Delta H_2 = 4.59$ cm H_2O

$T_{s_3} = 147°C$ (R/S)

$\Delta p_3 = 9.75$ cm H_2O

R/S $\rightarrow \Delta H_3 = 4.43$ cm H_2O

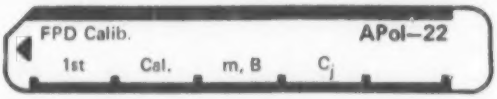
Tabulated ΔH_i (cm H_2O):

	1	2	3	4	5	6
Port A	4.31	4.59	4.43	4.37	4.30	4.22
Port B	4.39	4.46	4.43	4.40	4.29	4.24

LINE	INSTRUCTIONS	DATA	KEYS	DISPLAY
1	a. Load program card			
	b. Enter, as program steps, the correct			
	value for K' from equation (21-2).			
2	Store variables (°C)	T_s	A	1
		JD_o^2	↑	
		P_s/P_m	↑	
		C_p	R/S	2
		B_d	↑	
		M_d	↑	

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
	(°C)	T_m	↑		
		M_s	R/S		3
3	a. Calculate stack velocity	(C_p)	STO	1	
		(M_s)	STO	7	
		(T_s)	STO	8	
	(cm H_2O)	Δp	B		
	b. Calculate nozzle size	(P_s/P_m)	STO	4	
		(B_d)	STO	5	
		(T_s)	STO	8	
		(T_m)	STO	9	
		(V_s)	↑		
		Q_m	R/S		D_N
	c. Select the next smaller available	D_N'	STO	3	
	nozzle size, D_N'				
	d. Compute isokinetic run data	(C_p)	STO	1	
	$(\Delta H_i, \Delta p_i)$	(JD_o^2)	STO	2	
		(D_N')	STO	3	
		(P_s/P_m)	STO	4	
		(B_d)	STO	5	
		(M_d)	STO	6	
		(M_s)	STO	7	
		(T_s)	STO	8	
		(T_m)	STO	9	
	(cm H_2O)	Δp_i	C		ΔH_i
	e. For subsequent Run Data when all				
	variables except Δp_i and T_{s_i} are				
	unchanged (°C)	T_{s_i}	A		1
	(cm H_2O)	Δp_i	C		ΔH_i
	(Note: All storage registers are				
	protected from overwrite. When				
	individual variables are stored,				
	Line 2 may be omitted.)				

FLAME PHOTOMETRIC DETECTOR CALIBRATION BY PERMEATION TUBE TECHNIQUE



The calibration of a flame photometric detector (FPD) by use of a permeation tube has been described by R. K. Stephens.[1] For a continuous flow of gas over the permeation tube, the concentration, in parts per million (ppm), of permeand contained in the carrier gas flowing over the tube is given by:

$$C = \frac{Pr}{M} \times \frac{G}{L} \qquad (22\text{-}1)$$

where

C = concentration of permeand transferred to a gas flowing over the permeation tube, ppm

Pr = permeation rate (from gravimetric determination of weight loss due to permeation), μg/min

M = molecular weight of the gas inside the permeation tube, g/g-mole

G = volume per g-mole, as given by the ideal gas law, for this gas at a stated temperature and pressure, liters/g-mole (G = 24.1 l/g-mole at 20.3°C and one atm)

L = flow rate of the clean dilution air, liters/min

By adjusting the dilution air flow rate (L) one can obtain the desired permeand concentration.

For sulfur dioxide, hydrogen sulfide, methyl mercaptan, and carbon disulfide the instrument response (of the FPD) and the concentration (of the gas) are linear in the natural log, thus:

$$\ln C = m \times \ln(\text{Instrument Response}) + B \qquad (22\text{-}2)$$

where

ln C = natural logarithm of the concentration of the gas, for C in ppm

m = slope of the line as determined by calibration data

B = background value (i.e., y-intercept) as determined by calibration data

Instrument Response = magnitude of the response of the FPD to a certain concentration as given by the product of the attenuation and scale fraction (% scale/100%)

Thus the concentration associated with an instrument response is given by:

$$C = \exp\left\{m \times \ln(\text{Instrument Response}) + B\right\} \qquad (22\text{-}3)$$

where

C, m, Instrument Response, and B are as defined above.

For a given instrument the value for "m" and "B" are determined by calibration with a permeation tube. Equation (22-1) is used to calculate the concentration C_i that gives rise to an instrument response IR_i. By using several concentrations and ploting ln C_i vs ln IR_i the value of "m" and "B" can be determined from a least squares curve fit. Once "m" and "B" have been determined from the calibration data, equation (22-3) can be used to calculate unknown concentrations of this gaseous compounds.

Note: R = 0.08205 liter-atm/mole-K°

Reference:

1. Stephens, R. K., A. E. O'Keefe and G. C. Ortman, "Absolute Calibration of a Flame Photometric Detector to Volatile Sulfur Compounds at Sub-Part-Per-Million Levels". Environmental Science & Technology, 3, No. 7, pp. 652-55 (1969).

Example:

Calibration Data

SO_2 Permeation Tube No. 2 Instrument ID No. A96257

Pr = 2 μg/min
G = 24.1 l/min (20.3°C and 1.00 atm pressure)
M = 64 g/g-mole

(L ,	Attn ,	% Scale)
(0.81 l/min,	x 10^{-5},	75%)
(6.85 l/min,	x 10^{-7},	100%)
(10 l/min,	x 10^{-7},	53.6%)

→ m = 0.503
B = 5.87

Unknown Concentrations

(Attn ,	% Scale)	
(x 10^{-8},	65%)	→ C = 0.0268 ppm
(x 10^{-6},	90%)	→ C = 0.321 ppm

Calibration Data
(when IR is known directly)

Pr = 2 μg/min
G = 24.1 l/min (20.3°C and 1.00 atm pressure)
M = 64 g/g-mole

(L , 100, IR)
(0.84 l/min, 100, 5.6×10^{-6})
(3.80 l/min, 100, 3.2×10^{-7})
(23.0 l/min, 100, 1.0×10^{-8})

→ m = 0.523
B = 6.21

LINE	INSTRUCTIONS	DATA	KEYS		DISPLAY
1	Load program card				
2	Determine calibration constants m & B				
	a. Initialize		f	REG	
	b. Store permeation tube constants	Pr	↑		
		G	↑		
		M	A		2
	c. Enter calibration data	L_i	↑		
	(when IR is known directly; enter	$Attn_i$	↑		
	100 for $Attn_i$ and enter the value for				
	IR_i in place of % $Scale_i$)	% $Scale_i$	B		i
	(Do i = 1, N for N calibration pts)				
	d. Calculate m and B		C		m
			c	x⇄y	B
3	Calculate unknown concentrations	(m)	STO	2	
		(B)	STO	3	
	(When IR_j is known directly; enter	$Attn_j$	↑		
	100 for $Attn_j$ and enter the value for				
	IR_j in place of % $Scale_j$)	% $Scale_j$	D		C_j
	(Do j = 1, K for K unknowns)				

SECTION V

APPENDICES

PAGE

A. Entering a Program Card 85

B. Brief Operating Instructions 86

C. Program Listings 87

D. Unit Conversion Table 115

APPENDIX A

ENTERING A PROGRAM CARD

To enter a program card set the W/PRGM – RUN switch to RUN with the OFF–ON switch in the ON position. Gently insert the card (printed side up) in the right, lower slot. When the card is part way in the motor engages it and passes it out the left side of the calculator. When the motor stops, remove the card from the left side of the calculator and insert it in the upper "window slot" on the right side of the calculator. The program is now stored in the calculator. It remains stored until another program card is entered, the calculator is turned off, or the W/PRGM–RUN switch is set in the W/PRGM position and any key (except [SST]) is pressed. When a program card is entered with the W/PRGM–RUN switch in the W/PRGM mode, the content of the magnetic card is overwritten by the program steps in the calculator memory (unless the corner of the card has been clipped to prevent overwrites). The program in the calculator is unaltered.

APPENDIX B

BRIEF OPERATING INSTRUCTIONS

The following gives a brief review of operating instructions for the HP-65. For more extensive instruction the reader is referred to the HP-65 owner's handbook.

Program cards should be entered with the W/PRGM-RUN switch in the RUN position (in the W/PRGM position the instructions in the machine are written onto the card). The [DSP] and [DSP] [·] keys are used to set the display to scientific notation or fixed decimal notation respectively. The negative number "–24" would be entered as follows: [2], [4], [CHS], [↑]. The number "2.4×10^{-6}" would be entered as [2], [·], [4], [EEX], [CHS], [6], [↑]. To clear a number from the X register (display register) without shifting the stack, use [CLX]. Numbers are stored and manipulated in the machine "registers". Each number, no matter how few digits or how many, occupies one entire register. The displayed X-register, which is the only visible register, is one of four registers inside the calculator that are positioned to form the automatic memory stack. We label these registers X, Y, Z, and T. They are "stacked" one on top of the other with the X-register on the bottom as illustrated below:

Name	Register
T	4
Z	5
Y	14
X	3

A two number function, such as [+], [–], [x], and [÷], would perform the specified operation on the contents of the Y and X registers, thus both numbers must be in the calculator before the function key is pressed. If the stack were loaded as shown above and the [–] key were pressed, the contents of the X-register would be subtracted from that of the Y-register.

$$\begin{array}{r} 14 \\ -\ 3 \\ \hline 11 \end{array}$$

Our new stack would look like this:

T	4
Z	4
Y	5
X	11

Notice that the 14 and 3 have been replaced by the 11 and the contents of the Z and T dropped down. The T maintains its old number even though it was dropped down to the Z-register. Thus a calculation such as 4 + 5 (2 x 7 – 3) could be performed from left to right by: [4], [↑], [5], [↑], [2], [↑], [7], [x], [3], [–] (at this point the stack is as shown above), [x], [+]. The answer 59.00 is displayed (X-register).

The above paragraph illustrates manipulations of the 4-register stack. General practice, however, is to start with the inner-most parentheses first and work outward, thus the above problem would normally be approached as follows: [2], [↑], [7], [x], [3] [−], [5], [x], [4], [+] which requires only 10 key strokes rather than 12.

A program is simply a sequence of keystrokes stored in the calculator and executed automatically when the operator presses a button (A, B, C, D, E, R/S), the same sequence being repeated each time one presses the buttons A, B, C, D, E. The bulk of the program steps will be the same keys one would press manually in RUN mode in order to solve the problem.

In RUN mode the [SST] key is used to execute the program one step at a time (single step). In W/PRGM mode this same key is used to review a program one step at a time. For example the key stroke [R/S] would be represented by the display code [84] because this key is located on the 8th row 4th column. A merged key stroke such as [RCL], [7] would be represented by the code [34 07]

The obvious advantage to using a programmable calculator is that for a large number of data sets we need only program the calculator once. We then enter each data set and push a button to display the corresponding answer (or whatever sequence of operations the Program Instruction section specifies), reloading only those values that change from set to set. Having the programs stored on magnetic cards further simplifies operations in that once the program has been loaded onto a Program Card, we need only enter this card into the machine. Thus it is possible when we only have a single set of data to benefit from the programmable capability of the machine since we need not manually reenter the program (such is not the case with the HP-25).

Do not use a typewriter to label a Program Card; use a pencil, ink pen, or indelible marker such as a "Sharpie® No. 49". To protect cards from accidental overwrites, clip the left hand corner. The keys [g], [DEL] are used to remove key strokes from program memory and the key [g], [NOP] means simply "do not perform any operations, pass on to the next instruction". In the W/PRGM mode, [00 00] is the top of memory marker and the presence of two dash marks in the display (ex. [− 84−]) indicates the bottom of memory (key stroke No. 100). When all 100 key strokes have been used a dash mark will light on the right hand margin (ex. [24−]) to indicate "Full Memory" and remind the user that additional keystroke entries cause some "Instructions" to be lost from memory. A multiple decimal point display indicates that only two to five minutes of operation time remain in the battery pack. Blinking lights indicate either the program card did not read properly (program memory will be cleared, card should be reentered) or an improper operation was attempted (such as division by zero or taking the square root of a negative number, etc.). See Figure 2-1 of the HP-65 handbook for a listing of invalid operations. The keys [g], [x⇌y], [R↓], [R↑] are used to manipulate the contents of the four register stack.

APPENDIX C

PROGRAM LISTINGS

METHOD 1

CODE	KEYS
23	LBL
11	A
33 03	STO 3
35 08	g R↓
33 02	STO 2
35 08	g R↓
33 01	STO 1
34 03	RCL 3
02	2
81	÷
33 08	STO 8
33 07	STO 7
34 01	RCL 1
34 02	RCL 2
02	2
81	÷
61	+
33 04	STO 4
23	LBL
01	1
34 04	RCL 4
15	E
51	–
84	R/S
35	g
83	DSZ
22	GTO
01	1
23	LBL
02	2
01	1
33	STO
61	+
08	8
15	E

CODE	KEYS
34 04	RCL 4
61	+
84	R/S
34 08	RCL 8
34 07	RCL 7
35 24	g x>y
22	GTO
02	2
00	0
24	RTN
23	LBL
15	E
34 08	RCL 8
02	2
71	x
01	1
51	–
34 03	RCL 3
81	÷
31	f
09	$\sqrt{x}$
34 02	RCL 2
71	x
02	2
81	÷
24	RTN
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	d	R_4	(work)	R_7	
R_2	D	R_5		R_8	(work)
R_3	K	R_6		R_9	

METHOD 2

CODE	KEYS
23	LBL
11	A
81	÷
31	f
09	$\sqrt{x}$
71	x
33 04	STO 4
84	R/S
23	LBL
14	D
35 09	g R ↑
35 09	g R ↑
61	+
83	•
02	2
08	8
71	x
35 07	g x⇌y
83	•
04	4
04	4
71	x
61	+
35 07	g x⇌y
83	•
03	3
02	2
71	x
61	+
33 06	STO 6
84	R/S
23	LBL
12	B
08	8
05	5

CODE	KEYS
83	•
04	4
08	8
33 01	STO 1
34 02	RCL 2
04	4
06	6
00	0
61	+
34 05	RCL 5
81	÷
34 07	RCL 7
01	1
08	8
71	x
01	1
34 07	RCL 7
51	–
34 06	RCL 6
71	x
61	+
81	÷
31	f
09	$\sqrt{x}$
34 03	RCL 3
71	x
34 04	RCL 4
71	x
34 01	RCL 1
71	x
33 08	STO 8
84	R/S
23	LBL
13	C
01	1

CODE	KEYS
07	7
83	•
06	6
05	5
34 05	RCL 5
71	x
34 02	RCL 2
04	4
06	6
00	0
61	+
81	÷
34	RCL
09	9
71	x
34 08	RCL 8
71	x
34 07	RCL 7
42	CHS
01	1
61	+
71	x
03	3
06	6
00	0
00	0
71	x
84	R/S
22	GTO
12	B

R_1	85.48	R_4	C_p	R_7	B_{wo}
R_2	$(T_s)_{avg}$	R_5	P_s	R_8	$(V_s)_{avg}$
R_3	$(\sqrt{\Delta p})_{avg}$	R_6	M_d	R_9	A

METHOD 3

CODE	KEYS
23	LBL
11	A
33 04	STO 4
35 08	g R ↓
33 03	STO 3
35 08	g R ↓
33 02	STO 2
35 08	g R ↓
33 01	STO 1
03	3
41	↑
84	R/S
23	LBL
12	B
34 03	RCL 3
34 01	RCL 1
83	•
05	5
71	x
51	–
34 02	RCL 2
83	•
02	2
06	6
04	4
71	x
34 03	RCL 3
51	–
34 01	RCL 1
83	•
05	5
71	x
61	+
81	÷
43	EEX

CODE	KEYS
02	2
71	x
84	R/S
23	LBL
13	C
34 04	RCL 4
83	•
04	4
04	4
71	x
34 03	RCL 3
83	•
03	3
02	2
71	x
61	+
34 02	RCL 2
34 01	RCL 1
61	+
83	•
02	2
08	8
71	x
61	+
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	%CO	R_4	$\%CO_2$	R_7
R_2	$\%N_2$	R_5		R_8
R_3	$\%O_2$	R_6		R_9

METHOD 4

CODE	KEYS
23	LBL
11	A
33 02	STO 2
35 08	g R ↓
33 01	STO 1
02	2
84	R/S
33 05	STO 5
35 08	g R ↓
33 04	STO 4
35 08	g R ↓
33 03	STO 3
03	3
41	↑
84	R/S
23	LBL
12	B
34 01	RCL 1
34 02	RCL 2
51	–
83	•
00	0
04	4
07	7
04	4
71	x
33 06	STO 6
84	R/S
23	LBL
13	C
34 03	RCL 3
34 04	RCL 4
71	x
34 05	RCL 5
04	4

CODE	KEYS
06	6
00	0
61	+
81	÷
01	1
07	7
83	•
06	6
05	5
71	x
33 07	STO 7
84	R/S
23	LBL
14	D
34 06	RCL 6
34 06	RCL 6
34 07	RCL 7
61	+
81	÷
83	•
00	0
02	2
05	5
61	+
33 08	STO 8
84	R/S
22	GTO
12	B
23	LBL
15	E
41	↑
02	2
08	8
83	•
03	3

CODE	KEYS
02	2
71	x
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	V_f	R_4	P_m	R_7	V_{me}
R_2	V_i	R_5	T_m	R_8	B_{wo}
R_3	V_m	R_6	V_{wc}	R_9	

METHOD 5
CARD A

CODE	KEYS
23	LBL
11	A
33 04	STO 4
35 08	g R ↓
33 03	STO 3
35 08	g R ↓
33 02	STO 2
35 08	g R ↓
33 01	STO 1
01	1
84	R/S
33 06	STO 6
35 08	g R ↓
33 05	STO 5
02	2
84	R/S
23	LBL
12	B
34 03	RCL 3
01	1
03	3
83	•
06	6
81	÷
34 02	RCL 2
61	+
34 04	RCL 4
04	4
06	6
00	0
61	+
81	÷
34 01	RCL 1
71	x
01	1

CODE	KEYS
07	7
83	•
06	6
05	5
71	x
33 07	STO 7
84	R/S
34 05	RCL 5
83	•
00	0
04	4
07	7
02	2
71	x
84	R/S
41	↑
41	↑
34 07	RCL 7
61	+
81	÷
84	R/S
23	LBL
13	C
34 06	RCL 6
34 07	RCL 7
81	÷
83	•
00	0
01	1
05	5
04	4
71	x
84	R/S
23	LBL
14	D

CODE	KEYS
34 06	RCL 6
34 07	RCL 7
81	÷
02	2
02	2
00	0
05	5
43	EEX
42	CHS
09	9
71	x
84	R/S
23	LBL
15	E
34 06	RCL 6
34 07	RCL 7
81	÷
83	•
00	0
03	3
05	5
02	2
08	8
71	x
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	V_m	R_4	T_m	R_7	$V_{m_{std}}$
R_2	P_{bar}	R_5	V_{ℓ_c}	R_8	
R_3	ΔH	R_6	M_n	R_9	

METHOD 5
CARD B

CODE	KEYS
23	LBL
11	A
71	x
35 07	g x⇌y
04	4
06	6
00	0
61	+
35 07	g x⇌y
81	÷
01	1
83	•
06	6
06	6
07	7
71	x
01	1
84	R/S
71	x
81	÷
33 08	STO 8
34 03	RCL 3
01	1
03	3
83	•
06	6
81	÷
34 02	RCL 2
61	+
34 01	RCL 1
71	x
34 04	RCL 4
04	4
06	6
00	0

CODE	KEYS
61	+
81	÷
34 05	RCL 5
83	•
00	0
00	0
02	2
06	6
07	7
71	x
61	+
34 08	RCL 8
71	x
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	V_m	R_4	T_m	R_7	
R_2	P_{bar}	R_5	$V\ell_c$	R_8	(work)
R_3	ΔH	R_6		R_9	

METHOD 6

CODE	KEYS
23	LBL
11	A
33 03	STO 3
35 08	g R ↓
33 02	STO 2
35 08	g R ↓
33 01	STO 1
01	1
84	R/S
33 06	STO 6
35 08	g R ↓
33 05	STO 5
35 08	g R ↓
33 04	STO 4
02	2
84	R/S
33 08	STO 8
35 08	g R ↓
33 07	STO 7
03	3
84	R/S
23	LBL
12	B
34 01	RCL 1
34 02	RCL 2
71	x
34 03	RCL 3
04	4
06	6
00	0
61	+
81	÷
01	1
07	7
83	•

CODE	KEYS
06	6
05	5
71	x
33	STO
09	9
84	R/S
23	LBL
13	C
34 04	RCL 4
34 05	RCL 5
51	–
34 06	RCL 6
71	x
34 07	RCL 7
71	x
34 08	RCL 8
81	÷
34	RCL
09	9
81	÷
07	7
00	0
05	5
43	EEX
42	CHS
07	7
71	x
84	R/S
22	GTO
12	B
23	LBL
14	D
41	↑
01	1
06	6

CODE	KEYS
00	0
02	2
00	0
71	x
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	V_m	R_4	V_t	R_7	V_{soln}
R_2	P_{bar}	R_5	V_{tb}	R_8	V_a
R_3	T_m	R_6	N	R_9	$V_{m_{std}}$

METHOD 7

CODE	KEYS
23	LBL
11	A
33 03	STO 3
35 08	g R ↓
33 02	STO 2
35 08	g R ↓
33 01	STO 1
02	2
84	R/S
33 06	STO 6
35 08	g R ↓
33 05	STO 5
35 08	g R ↓
33 04	STO 4
03	3
84	R/S
23	LBL
12	B
34 02	RCL 2
34 03	RCL 3
04	4
06	6
00	0
61	+
81	÷
34 04	RCL 4
34 05	RCL 5
04	4
06	6
00	0
61	+
81	÷
51	–
34 01	RCL 1
02	2

CODE	KEYS
05	5
51	–
71	x
01	1
07	7
83	·
06	6
05	5
71	x
33 07	STO 7
84	R/S
23	LBL
13	C
34 06	RCL 6
34 07	RCL 7
81	÷
06	6
02	2
43	EEX
42	CHS
06	6
71	x
84	R/S
22	GTO
12	B
23	LBL
14	D
41	↑
01	1
06	6
00	0
02	2
00	0
71	x
84	R/S

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	V_f	R_4	P_i	R_7	V_{sc}
R_2	P_f	R_5	T_i	R_8	
R_3	T_f	R_6	m	R_9	

METHOD 8

CODE	KEYS
33 04	STO 4
35 08	g R ↓
33 03	STO 3
35 08	g R ↓
33 02	STO 2
35 08	g R ↓
33 01	STO 1
01	1
84	R/S
33 07	STO 7
35 08	g R ↓
33 06	STO 6
35 08	g R ↓
33 05	STO 5
02	2
84	R/S
33	STO
09	9
35 08	g R ↓
33 08	STO 8
03	3
84	R/S
23	LBL
11	A
34 04	RCL 4
01	1
03	3
83	·
06	6
81	÷
34 02	RCL 2
61	+
34 03	RCL 3
04	4
06	6

CODE	KEYS
00	0
61	+
81	÷
34 01	RCL 1
71	x
01	1
07	7
83	·
06	6
05	5
71	x
24	RTN
23	LBL
12	B
34 07	RCL 7
35 07	g x⇌y
81	÷
34 08	RCL 8
71	x
34	RCL
09	9
81	÷
34 05	RCL 5
34 06	RCL 6
51	–
71	x
24	RTN
23	LBL
13	C
11	A
12	B
01	1
00	0
08	8
43	EEX

CODE	KEYS
42	CHS
06	6
71	x
84	R/S
23	LBL
14	D
11	A
12	B
07	7
00	0
05	5
43	EEX
42	CHS
07	7
71	x
84	R/S
23	LBL
15	E
01	1
06	6
00	0
02	2
00	0
71	x
24	RTN
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	V_m	R_4	ΔH	R_7	N
R_2	P_{bar}	R_5	V_t	R_8	V_{soln}
R_3	T_m	R_6	V_{tb}	R_9	V_a

CASCADE IMPACTOR OPERATION

CODE	KEYS
23	LBL
11	A
34 07	RCL 7
02	2
08	8
71	X
34 08	RCL 8
04	4
04	4
71	x
61	+
34 04	RCL 4
03	3
02	2
71	x
61	+
33	STO
09	9
84	R/S
33 01	STO 1
01	1
35 07	g x⇌y
51	–
71	x
01	1
08	8
34 01	RCL 1
71	x
61	+
33 03	STO 3
84	R/S
23	LBL
12	B
41	↑
01	1

CODE	KEYS
03	3
83	·
06	6
81	÷
35 07	g x⇌y
33 06	STO 6
61	+
33 02	STO 2
84	R/S
23	LBL
13	C
01	1
34 01	RCL 1
51	–
34 02	RCL 2
71	x
32	f^{-1}
09	$\sqrt{x}$
34	RCL
09	9
71	x
33 05	STO 5
34 02	RCL 2
34 03	RCL 3
71	x
31	f
09	$\sqrt{x}$
33 03	STO 3
34 05	RCL 5
84	R/S
23	LBL
14	D
41	↑
04	4
06	6

CODE	KEYS
00	0
61	+
84	R/S
23	LBL
15	E
41	↑
09	9
71	x
05	5
81	÷
03	3
02	2
61	+
14	D
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	B_{wo}	R_4	B_{O_2}	R_7	$B_{N_2} + B_{CO}$
R_2	P_s	R_5	IR_1	R_8	B_{CO}
R_3	M_s, $\sqrt{P_s \cdot M_s}$	R_6	P_{bar}	R_9	M_d

CASCADE IMPACTOR OPERATION

CODE	KEYS
00	0
33 04	STO 4
33 05	STO 5
33 08	STO 8
33	STO
09	9
08	8
05	5
83	·
03	3
05	5
34 03	RCL 3
81	÷
34 01	RCL 1
71	x
33 06	STO 6
00	0
84	R/S
23	LBL
11	A
04	4
06	6
00	0
61	+
33 07	STO 7
33	STO
61	+
09	9
35 07	g x⇌y
33 02	STO 2
71	x
31	f
09	$\sqrt{x}$
34 06	RCL 6
71	x

CODE	KEYS
33 08	STO 8
33	STO
61	+
05	5
34 04	RCL 4
01	1
61	+
33 04	STO 4
34 08	RCL 8
84	R/S
34 02	RCL 2
84	R/S
34 07	RCL 7
04	4
06	6
00	0
51	–
84	R/S
34 04	RCL 4
84	R/S
22	GTO
11	A
23	LBL
12	B
32	f^{-1}
09	$\sqrt{x}$
34 05	RCL 5
34 04	RCL 4
81	÷
33 07	STO 7
71	x
05	5
83	·
00	0
07	7

CODE	KEYS
43	EEX
42	CHS
04	4
71	x
33 08	STO 8
84	R/S
34 07	RCL 7
84	R/S
34	RCL
09	9
34 04	RCL 4
81	÷
33 07	STO 7
84	R/S
23	LBL
15	E
34 07	RCL 7
33	STO
51	–
09	9
34 08	RCL 8
33	STO
51	–
05	5
34 04	RCL 4
01	1
51	–
33 04	STO 4
84	R/S
35 01	g NOP

R_1	c_p	R_4	n	R_7	T_i, $(V_s)_{avg}$, $(T_s)_{avg}$
R_2	Δp_i	R_5	ΣV_i	R_8	V_i, Q_i
R_3	$\sqrt{P_s \cdot M_s}$	R_6	θ	R_9	ΣT_i

100 APol-09C$_1$
ΔH, ΔH'

CASCADE IMPACTOR OPERATION

CODE	KEYS	
23	LBL	
11	A	
34 08	RCL 8	
34 07	RCL 7	
81	÷	
32	f^{-1}	
09	$\sqrt{x}$	
34 05	RCL 5	
71	x	
34 04	RCL 4	
71	x	
	c_c	***
71	x	
33 08	STO 8	
00	0	
84	R/S	
23	LBL	
12	B	
33 03	STO 3	
34 01	RCL 1	
14	D	
84	R/S	
01	1	
03	3	
83	·	
06	6	
81	÷	
34 03	RCL 3	
61	+	
34 02	RCL 2	
14	D	

CODE	KEYS	
84	R/S	*
34 07	RCL 7	
81	÷	
34 04	RCL 4	
71	x	
34	RCL	
09	9	
81	÷	
	c_c	***
81	÷	
31	f	
09	$\sqrt{x}$	
34 02	RCL 2	
71	x	
06	6	K
83	·	K
00	0	K
00	0	K
35 07	g x⇌y	
81	÷	
35 01	g NOP	**
23	LBL	
15	E	
34 03	RCL 3	
83	·	
05	5	
61	+	
84	R/S	
22	GTO	
12	B	
23	LBL	

CODE	KEYS
14	D
41	↑
71	x
34 08	RCL 8
34 06	RCL 6
35 09	g R ↑
11	−
33 07	STO 7
81	÷
35 07	g x⇌y
81	÷
24	RTN
23	LBL
13	C
41	↑
02	2
05	5
83	·
04	4
71	x
84	R/S
22	GTO
14	D
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

* R/S displays ΔH'
** R/S displays t
*** Enter value as determined from equation 9-2b

R_1	Q_{cal}	R_4	T_o	R_7	$(T_s)_{avg}$), P'_o
R_2	Q'_{cal}	R_5	IR_1	R_8	Q_l, γ
R_3	ΔP_{sys}	R_6	P_{bar}	R_9	M_d

CASCADE IMPACTOR OPERATION

CODE	KEYS	
23	LBL	
11	A	
34 08	RCL 8	
34 07	RCL 7	
81	÷	
32	f^{-1}	
09	$\sqrt{x}$	
34 05	RCL 5	
71	x	
34 04	RCL 4	
71	x	
	c_c	***
71	x	
33 08	STO 8	
00	0	
84	R/S	
23	LBL	
12	B	
33 03	STO 3	
34 01	RCL 1	
14	D	
84	R/S	
01	1	
03	3	
83	·	
06	6	
81	÷	
34 03	RCL 3	
61	+	
34 02	RCL 2	
14	D	

CODE	KEYS	
35 01	g NOP	*
34 07	RCL 7	
81	÷	
34 04	RCL 4	
71	x	
34	RCL	
09	9	
81	÷	
	c_c	***
81	÷	
31	f	
09	$\sqrt{x}$	
34 02	RCL 2	
71	x	
	K	†
35 07	g x⇄y	
81	÷	
84	R/S	**
23	LBL	
15	E	
34 03	RCL 3	
83	·	
05	5	
61	+	
84	R/S	
22	GTO	
12	B	
23	LBL	

CODE	KEYS
14	D
41	↑
71	x
34 08	RCL 8
34 06	RCL 6
35 09	g R ↑
51	−
33 07	STO 7
81	÷
35 07	g x⇄y
81	÷
24	RTN
23	LBL
13	C
41	↑
02	2
05	5
83	·
04	4
71	x
84	R/S
22	GTO
14	D
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

* R/S displays ΔH′
** R/S displays t
*** Enter value as determined from equation 9-2b
† Enter value as determined from Equation 9-4

R_1	Q_{cal}	R_4	T_o	R_7	$(T_s)_{avg}$, P'_o
R_2	Q'_{cal}	R_5	IR_1	R_8	Q_I, γ
R_3	ΔP_{sys}	R_6	P_{bar}	R_9	M_d

IMPACTOR FLOW RATE GIVEN ORIFICE ΔH

CODE	KEYS
23	LBL
15	E
61	+
02	2
08	8
71	x
35 07	g x⇌y
04	4
04	4
71	x
61	+
35 07	g x⇌y
03	3
02	2
71	x
61	+
33 07	STO 7
84	R/S
23	LBL
14	D
01	1
03	3
83	·
06	6
81	÷
34 06	RCL 6
61	+
33 05	STO 5
84	R/S
23	LBL
11	A
34 06	RCL 6
35 07	g x⇌y
51	–
71	x

CODE	KEYS
34 07	RCL 7
81	÷
34 02	RCL 2
04	4
06	6
00	0
61	+
81	÷
	c_c *
81	÷
31	f
09	$\sqrt{x}$
34 03	RCL 3
04	4
06	6
00	0
61	+
71	x
34 01	RCL 1
71	x
34 05	RCL 5
81	÷
01	1
34 04	RCL 4
51	–
81	÷
84	R/S
22	GTO
11	A
23	LBL
13	C

CODE	KEYS
41	↑
02	2
08	8
83	·
03	3
02	2
71	x
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

* Enter value as determined from equation 10-2

R_1	Q_{cal}	R_4	B_{wo}	R_7	M_d
R_2	T_o	R_5	P_s	R_8	ΔH
R_3	T_s	R_6	P_{bar}	R_9	ΔP_{sy}

IMPACTOR FLOW RATE, GIVEN GAS VELOCITY AND NOZZLE DIAMETER

CODE	KEYS
23	LBL
11	A
34 01	RCL 1
05	5
83	·
00	0
07	7
02	2
43	EEX
42	CHS
04	4
71	x
34 02	RCL 2
71	x
34 02	RCL 2
71	x
84	R/S
23	LBL
12	B
34 01	RCL 1
83	·
02	2
03	3
09	9
04	4
71	x
34 02	RCL 2
71	x
34 02	RCL 2
71	x
84	R/S
23	LBL
13	C
34 01	RCL 1
83	·

CODE	KEYS
00	0
01	1
04	4
03	3
06	6
71	x
34 02	RCL 2
71	x
34 02	RCL 2
71	x
24	RTN
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	$(V_s)_{avg}$	R_4	R_7
R_2	D_N	R_5	R_8
R_3		R_6	R_9

IMPACTOR SAMPLING TIME TO COLLECT 50 MILLIGRAMS

CODE	KEYS
23	LBL
11	A
83	•
07	7
07	7
01	1
06	6
02	2
14	D
24	RTN
23	LBL
13	C
01	1
07	7
06	6
05	5
83	•
07	7
14	D
24	RTN
23	LBL
14	D
34 01	RCL 3
81	÷
34 02	RCL 8
81	÷
35 01	g NOP } *
06	6
00	0
81	÷
21	DSP
83	•
04	4
31	f
03	→ D. MS

CODE	KEYS
24	RTN
23	LBL
15	E
41	↑
07	7
00	0
00	0
00	0
71	x
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

*Optional R/S

R_1	R_4	R_7
R_2	R_5	R_8 q_l
R_3 G or G'	R_6	R_9

IMPACTOR FLOW RATE, SAMPLE VOLUME, MASS LOADING

CODE	KEYS
23	LBL
11	A
35 09	g R ↑
33 08	STO 8
35 08	g R ↓
01	1
03	3
83	•
06	6
81	÷
61	+
33 07	STO 7
44	CLX
34 08	RCL 8
81	÷
33 06	STO 6
84	R/S
34 02	RCL 2
04	4
06	6
00	0
61	+
34 04	RCL 4
04	4
06	6
00	0
61	+
81	÷
01	1
34 01	RCL 1
51	–
81	÷
34 03	RCL 3
81	÷
34 05	RCL 5

CODE	KEYS
34 07	RCL 7
51	–
71	x
34 06	RCL 6
71	x
33 06	STO 6
84	R/S
34 06	RCL 6
34 08	RCL 8
71	x
33 06	STO 6
84	R/S
34 06	RCL 6
01	1
34 01	RCL 1
51	–
71	x
34 03	RCL 3
71	x
34 02	RCL 2
04	4
06	6
00	0
61	+
81	÷
01	1
07	7
83	•
06	6
05	5
71	x
33	STO
09	9
24	RTN
23	LBL

CODE	KEYS
13	C
34	RCL
09	9
81	÷
83	•
00	0
01	1
05	5
04	4
03	3
71	x
84	R/S
34	RCL
09	9
71	x
34 06	RCL 6
81	÷
24	RTN
23	LBL
15	E
41	↑
01	1
03	3
83	•
06	6
81	÷
24	RTN
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	B_{wo}	R_4	T_m	R_7	ΔP_m
R_2	T_s	R_5	P_{bar}	R_8	t
R_3	P_s	R_6 work register	Q_m, Q_A, V_A	R_9	V_N

IMPACTOR STAGE D_{50}

CODE	KEYS
33 07	STO 7
71	x
61	+
43	EEX
42	CHS
06	6
71	x
33 03	STO 3
01	1
84	R/S
71	x
71	x
33 05	STO 5
02	2
84	R/S
23	LBL
15	E
33 04	STO 4
35 08	g R ↓
33 08	STO 8
01	1
83	·
05	5
33 02	STO 2
35 08	g R ↓
35 08	g R ↓
34 07	RCL 7
71	x
01	1
61	+
31	f
09	$\sqrt{x}$
34 03	RCL 3
71	x
34 04	RCL 4

CODE	KEYS
81	÷
01	1
83	·
00	0
04	4
71	x
33 01	STO 1
23	LBL
09	9
34 03	RCL 3
34 04	RCL 4
71	x
34 05	RCL 5
81	÷
34 02	RCL 2
81	÷
31	f
09	$\sqrt{x}$
34 08	RCL 8
71	x
33 06	STO 6
34 01	RCL 1
81	÷
83	·
04	4
04	4
71	x
42	CHS
32	f^{-1}
07	LN
83	·
04	4
01	1
71	x
01	1

CODE	KEYS
83	·
02	2
03	3
61	+
02	2
71	x
34 01	RCL 1
71	x
34 06	RCL 6
81	÷
01	1
61	+
34 02	RCL 2
35 07	g x⇌y
33 02	STO 2
81	÷
01	1
51	−
35	g
06	ABS
83	·
00	0
00	0
01	1
35 22	g x≤y
22	GTO
09	9
34 06	RCL 6
84	R/S
35 01	g NOP

R_1	L	R_4	P_s	R_7	T
R_2	C_i	R_5	$(Q \quad \rho_p \quad P_a)$	R_8	K_s
R_3	μ	R_6	D_{50i}	R_9	(work)

$\sqrt{V}$ CALCULATION–ROUND JETS

CODE	KEYS
33 02	STO 2
35 08	g R ↓
03	3
35	g
05	y^x
71	x
33 03	STO 3
01	1
34	R/S
33 07	STO 7
71	x
61	+
43	EEX
42	CHS
06	6
71	x
33 06	STO 6
02	2
84	R/S
71	x
71	x
33 05	STO 5
03	3
84	R/S
23	LBL
15	E
43	EEX
04	4
42	CHS
71	x
33 01	STO 1
83	·
00	0
00	0
03	3

CODE	KEYS
06	6
07	7
34 07	RCL 7
71	x
01	1
61	+
31	f
09	$\sqrt{x}$
34 06	RCL 6
71	x
34 02	RCL 2
81	÷
01	1
83	·
00	0
04	4
71	x
33 04	STO 4
23	LBL
13	C
34 01	RCL 1
81	÷
41	↑
35	g
04	1/x
83	·
04	4
04	4
71	x
42	CHS
32	f^{-1}
07	LN
83	·
08	8
02	2

CODE	KEYS
71	x
02	2
83	·
04	4
06	6
61	+
71	x
01	1
61	+
34 05	RCL 5
71	x
83	·
00	0
07	7
00	0
07	7
71	x
34 06	RCL 6
81	÷
34 02	RCL 2
81	÷
34 03	RCL 3
81	÷
31	f
09	$\sqrt{x}$
34 01	RCL 1
71	x
84	R/S
22	GTO
15	E

R_1	D_{p_j}	R_4	L	R_7	T
R_2	P_s	R_5	$(Q \quad \rho_p \quad P_A)$	R_8	
R_3	$(D_c^3 \cdot X)$	R_6	μ	R_9	

$\sqrt{\Psi}$ CALCULATION–RECTANGULAR SLOTS

CODE	KEYS
33 02	STO 2
35 08	g R ↓
02	2
35	g
05	y^x
71	x
33 03	STO 3
01	1
84	R/S
33 07	STO 7
71	x
61	+
43	EEX
42	CHS
06	6
71	x
33 06	STO 6
02	2
84	R/S
71	x
71	x
33 05	STO 5
03	3
84	R/S
23	LBL
15	E
43	EEX
04	4
42	CHS
71	x
33 01	STO 1
83	·
00	0
00	0
03	3

CODE	KEYS
06	6
07	7
34 07	RCL 7
71	x
01	1
61	+
31	f
09	$\sqrt{x}$
34 06	RCL 6
71	x
34 02	RCL 2
81	÷
01	1
83	·
00	0
04	4
71	x
33 04	STO 4
23	LBL
13	C
34 01	RCL 1
81	÷
41	↑
35	g
04	1/x
83	·
04	4
04	4
71	x
42	CHS
32	f^{-1}
07	LN
83	·
08	8
02	2

CODE	KEYS
71	x
02	2
83	·
04	4
06	6
61	+
71	x
01	1
61	+
34 05	RCL 5
71	x
83	·
00	0
05	5
05	5
06	6
71	x
34 06	RCL 6
81	÷
34 02	RCL 2
81	÷
34 03	RCL 3
81	÷
31	f
09	$\sqrt{x}$
34 01	RCL 1
71	x
84	R/S
22	GTO
15	E

R_1	D_{p_j}	R_4	L	R_7	T
R_2	P_s	R_5	$(Q \quad \rho_p \quad P_A)$	R_8	
R_3	$(w^2 \ell)$	R_6	μ	R_9	

CUMULATIVE CONCENTRATION vs. D_{50} AND $\Delta M/\Delta \log D$ vs. GEOMETRIC MEAN DIAMETER

CODE	KEYS
23	LBL
11	A
33 04	STO 4
35 08	g R ↓
33 03	STO 3
35 08	g R ↓
33 02	STO 2
35 08	g R ↓
83	•
00	0
02	2
08	8
03	3
02	2
71	x
33 01	STO 1
00	0
41	↑
84	R/S
23	LBL
12	B
21	DSP
83	•
02	2
33 06	STO 6
35 08	g R ↓
33 05	STO 5
83	•
04	4
03	3
07	7
01	1
33 08	STO 8
06	6
02	2

CODE	KEYS
04	4
02	2
43	EEX
42	CHS
08	8
33	STO
09	9
34 02	RCL 2
84	R/S
34 03	RCL 3
84	R/S
34 07	RCL 7
21	DSP
02	2
84	R/S
34 03	RCL 3
34 05	RCL 5
71	x
31	f
09	$\sqrt{x}$
21	DSP
83	•
02	2
84	R/S
34 04	RCL 4
34 01	RCL 1
81	÷
33	STO
61	+
07	7
34 05	RCL 5
31	f
08	LOG
34 03	RCL 3
31	f

CODE	KEYS
08	LOG
51	–
81	÷
01	1
41	↑
33	STO
51	–
02	2
34 05	RCL 5
33 03	STO 3
44	CLX
34 06	RCL 6
33 04	STO 4
35 09	g R ↑
21	DSP
02	2
84	R/S
22	GTO
12	B
23	LBL
13	C
83	•
00	0
02	2
08	8
03	3
02	2
71	x
24	RTN
35 01	g NOP

R_1	V_T	R_4	m_i	R_7	$c_{i,cum}$
R_2	i	R_5	D_{i-1}	R_8	0.4371
R_3	D_i	R_6	m_{i-1}	R_9	6.242×10^{-8}

MEAN, STANDARD DEVIATION, 90/95% CONFIDENCE INTERVAL, MEAN ±CI

CODE	KEYS
23	LBL
11	A
33	STO
61	+
05	5
32	f^{-1}
09	$\sqrt{x}$
33	STO
61	+
06	6
34 04	RCL 4
01	1
61	+
33 04	STO 4
84	R/S
22	GTO
11	A
23	LBL
15	E
33	STO
51	–
05	5
32	f^{-1}
09	$\sqrt{x}$
33	STO
51	–
06	6
34 04	RCL 4
01	1
51	–
33 04	STO 4
24	RTN
23	LBL
12	B
34 06	RCL 6

CODE	KEYS
34 05	RCL 5
34 04	RCL 4
81	÷
33 07	STO 7
84	R/S
32	f^{-1}
09	$\sqrt{x}$
34 04	RCL 4
71	x
51	–
34 04	RCL 4
01	1
51	–
81	÷
31	f
09	$\sqrt{x}$
33 08	STO 8
84	R/S
34 07	RCL 7
81	÷
24	RTN
23	LBL
13	C
34 08	RCL 8
34 04	RCL 4
31	f
09	$\sqrt{x}$
81	÷
34 04	RCL 4
01	1
51	–
34 03	RCL 3
35	g
05	y^x
34 02	RCL 2

CODE	KEYS
71	x
34 01	RCL 1
61	+
71	x
33	STO
09	9
84	R/S
34 07	RCL 7
34	RCL
09	9
51	–
84	R/S
34 07	RCL 7
34	RCL
09	9
61	+
84	R/S
23	LBL
14	D
00	0
33 04	STO 4
33 05	STO 5
33 06	STO 6
84	R/S
22	GTO
11	A
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	c_1	R_4	n, N	R_7	$\bar{x}$
R_2	c_2	R_5	ΣX_i	R_8	σ
R_3	c_3	R_6	ΣX_i^2	R_9	CI

RESISTIVITY AND ELECTRIC FIELD STRENGTH

CODE	KEYS
23	LBL
11	A
33 04	STO 4
35 07	g x⇌y
33 03	STO 3
35 07	g x⇌y
81	÷
34 01	RCL 1
71	x
34 02	RCL 2
81	÷
84	R/S
23	LBL
15	E
34 03	RCL 3
34 02	RCL 2
81	÷
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	A	R_4	I	R_7	
R_2	L	R_5		R_8	
R_3	V	R_6		R_9	

CHANNEL CONCENTRATIONS; DC–1

CODE	KEYS
23	LBL
11	A
33 02	STO 2
35 08	g R ↓
33 01	STO 1
01	1
84	R/S
23	LBL
13	C
34 02	RCL 2
34 01	RCL 1
02	2
71	×
34 06	RCL 6
61	+
81	÷
34 04	RCL 4
81	÷
34 03	RCL 3
81	÷
34 05	RCL 5
81	÷
33 07	STO 7
84	R/S
22	GTO
11	A
23	LBL
12	B
33 04	STO 4
35 08	g R ↓
33 03	STO 3
02	2
84	R/S
33 06	STO 6
35 08	g R ↓

CODE	KEYS
33 05	STO 5
03	3
84	R/S
22	GTO
13	C
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	D_i	R_4	V	R_7	
R_2	N_i	R_5	ℓ	R_8	
R_3	t	R_6	d	R_9	

AEROTHERM STACK SAMPLER; STACK VELOCITY, NOZZLE DIAMETER, ISOKINETIC ΔH

CODE	KEYS
33 08	STO 8
01	1
84	R/S
33 01	STO 1
35 08	g R ↓
33 04	STO 4
35 08	g R ↓
33 02	STO 2
02	2
84	R/S
33 07	STO 7
35 08	g R ↓
33	STO
09	9
35 08	g R ↓
33 06	STO 6
35 08	g R ↓
33 05	STO 5
03	3
84	R/S
23	LBL
12	B
34 08	RCL 8
15	E
71	x
34 07	RCL 7
81	÷
31	f
09	$\sqrt{x}$
34 01	RCL 1
71	x
04	4 } K'
83	· } K'
00	0 } K'
03	3 } K'

CODE	KEYS
07	7
71	x
41	↑
84	R/S
34 08	RCL 8
15	E
71	x
35 07	g x⇌y
81	÷
34 05	RCL 5
81	÷
34	RCL
09	9
15	E
81	÷
34 04	RCL 4
81	÷
31	f
09	$\sqrt{x}$
83	·
04	4
06	6
71	x
24	RTN
23	LBL
13	C
34	RCL
09	9
15	E
71	x
34 08	RCL 8
15	E
81	÷
34 03	RCL 3
32	f^{-1}

CODE	KEYS
09	$\sqrt{x}$
34 01	RCL 1
71	x
34 05	RCL 5
71	x
34 02	RCL 2
81	÷
32	f^{-1}
09	$\sqrt{x}$
71	x
34 04	RCL 4
71	x
34 06	RCL 6
71	x
34 07	RCL 7
81	÷
84	R/S
33 08	STO 8
84	R/S
22	GTO
13	C
23	LBL
15	E
02	2
07	7
03	3
83	·
02	2
61	+
24	RTN

R_1	C_p	R_4	P_s/P_m	R_7	M_s
R_2	JD_o^2	R_5	B_d	R_8	T_s
R_3	D_N'	R_6	M_d	R_9	T_m

FPD CALIBRATION BY PERMEATION TUBE TECHNIQUE

CODE	KEYS
23	LBL
11	A
81	÷
71	x
33 01	STO 1
02	2
84	R/S
23	LBL
12	B
15	E
71	x
31	f
07	LN
33	STO
61	+
05	5
41	↑
41	↑
71	x
33	STO
61	+
04	4
35 08	g R ↓
35 07	g x⇌y
35	g
04	1/x
34 01	RCL 1
71	x
31	f
07	LN
33	STO
61	+
06	6
71	x
33	STO

CODE	KEYS
61	+
07	7
01	1
33	STO
61	+
08	8
34 08	RCL 8
84	R/S
22	GTO
12	B
23	LBL
13	C
34 07	RCL 7
34 05	RCL 5
34 06	RCL 6
71	x
34 08	RCL 8
81	÷
51	–
34 04	RCL 4
34 05	RCL 5
32	f^{-1}
09	$\sqrt{x}$
34 08	RCL 8
81	÷
51	–
81	÷
33 02	STO 2
34 05	RCL 5
34 08	RCL 8
81	÷
71	x
34 06	RCL 6
34 08	RCL 8
81	÷

CODE	KEYS
35 07	g x⇌y
51	–
33 03	STO 3
34 02	RCL 2
84	R/S
23	LBL
14	D
15	E
71	x
31	f
07	LN
34 02	RCL 2
71	x
34 03	RCL 3
61	+
32	f^{-1}
07	LN
84	R/S
22	GTO
14	D
23	LBL
15	E
01	1
00	0
00	0
81	÷
24	RTN
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	$(\frac{Pr\ G}{M})$	R_4	Σx^2	R_7	Σxy
R_2	m	R_5	Σx	R_8	n
R_3	B	R_6	Σy	R_9	

APPENDIX D

UNIT CONVERSION TABLE

English to Metric

1 in	=	25.40 mm = 2.540 cm
1 ft	=	0.3048 m
1 ft^3	=	0.02832 m^3 = 28.32 liters
1 lb	=	453.6 gm
1 grain	=	0.06480 gm
1 lb/ft^3	=	1.602×10^4 gm/m^3
1 gr/ft^3	=	2.288 gm/m^3

Metric to English

1 cm	=	0.3937 in.
1 m	=	3.281 ft
1 m^3	=	35.31 ft^3
1 gm	=	0.002205 lb
1 gm	=	15.43 grains
1 gm/m^3	=	6.243×10^{-5} lb/ft^3
1 gm/m^3	=	0.4370 gr/ft^3

Others

$1m^3$	=	10^3 liters = 10^6 cm^3
$1\mu m$	=	10^{-6} m = 10^4 Å
1 lb	=	7,000 grains
1 in. Hg	=	13.6 in. H_2O
R	=	0.08205 liter-atm/mole–K
1 gm/gm-mole	=	1 lb/lb-mole = 1 amu
°R	=	°F + 460
°K	=	°C + 273.2
°C	=	(5/9) (°F – 32)
°F	=	(9/5) °C + 32
1 ft/sec	=	0.6818 miles/hr

Engineering Standard or Normal conditions are 20.0°C, 760 Torr, (68°F, 29.92 in. Hg) on a dry basis.

$V_{(21.1°C)} = 1.0038 \quad V_{(20.0°C)}$

$V_{(20.0°C)} = 0.9962 \quad V_{(21.1°C)}$